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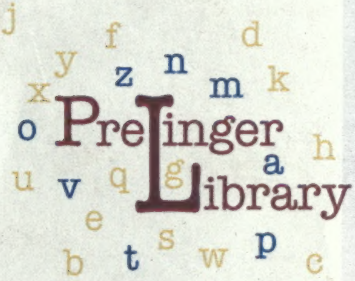

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RELATION OF MATURITY AND HANDLING OF BARTLETT PEARS IN THE PACIFIC NORTHWEST TO QUALITY OF THE CANNED PRODUCT

By B. D. EZELL, *assistant horticulturist*, and H. C. DIEHL, *senior physiologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry*[1]

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INTRODUCTION

The increased acreage planted to all varieties of pears in the Pacific Coast States during the past decade, which is being reflected in the increased tonnage, makes it evident that there must be an increased outlet if the growers of these pears are to continue in the business. Although the total yield has varied greatly from year to year, there has been a marked tendency toward increased production, which will be further augmented as the younger trees reach full-bearing age. For the 5-year period 1921–25 the average annual production of pears in California, Oregon, and Washington was 216,897 tons,[2] with a maximum crop of 272,208 tons in 1925. For the 6 years 1926–31 the average annual production was 353,440 tons, the largest crop being 445,928 tons in 1930 (*15*).[3]

One of the leading pear varieties grown in the Northwest is the Bartlett, but owing to its short storage period it cannot be successfully

[1] The writers wish to express their appreciation to J. S. Caldwell, senior physiologist, Division of Fruits and Vegetable Crops and Diseases, for helpful suggestions and criticisms; also to Libby, McNeill & Libby (in whose plant at Yakima, Wash., the experimental canning was done) for helpful cooperation, and especially to the personnel of the Yakima plant for assistance in the preparation and processing of the pear. Mention should also be made of the helpful interest and assistance given by the secretary and members of the Northwest Canners Association.

[2] On the basis of 1 bushel—48 pounds.

[3] Italic numbers in parentheses refer to Literature Cited, p. 23.

stored and marketed throughout the winter season. However, the Bartlett is the variety most desired by the canning trade, and a large percentage of the crop of this variety grown in the Pacific Northwest is taken by the canners.

In the Yakima and Wenatchee Valley districts of Washington during the years 1928 to 1931, inclusive, the Bartlett represented 67 percent of all pears shipped,[4] exclusive of those delivered direct to the canneries by the growers. The latter item would probably bring the percentage of Bartletts to 75 percent of the total pear crop. Data furnished by the Northwest Canners Association show that with an average crop of 55,500 tons of Bartletts produced in these districts during these 4 years, 39,850 tons, or 71.8 percent, were taken by the canneries. Comparable figures for Oregon show that with an average Bartlett crop of 23,000 tons, 12,625 tons (54.9 percent) were taken by the canneries. These figures will vary from year to year, depending upon the relative prices offered by the canner and by the fresh-fruit buyer. As production increases, it seems likely that an even larger percentage of the crop will find its way to the canneries.

PURPOSE AND PLAN OF WORK

The estimated annual per capita consumption of canned pears is 0.55 pound compared with 3 pounds for peaches and 1.02 pounds for apples (*16*). If the use of canned pears is to be stimulated, factors affecting the quality of the canned product should be known, and the practices that give the best quality in the finished product should be followed. Experimental work as well as commercial experience has demonstrated clearly that the maturity of Bartlett pears at picking time has a decided influence upon the dessert quality of the fruit when it is ripened for immediate consumption, as well as upon the length of time the fruit can be held satisfactorily in storage.

The search for definite indices for harvesting pears at the proper stage of maturity has resulted in the selection of such factors as firmness of flesh, color of skin, and corking of the lenticels as the most satisfactory. Firmness is measured by the resistance, expressed in pounds, offered to the piercing of the flesh with a steel plunger of a standard size to a definite depth (*7*, *9*). This index has been commonly called the pressure test. Experiments conducted by Magness, Diehl, and Allen (*6*), Hartman (*2*), and Hartman, Reimer, and Norris (*3*) have shown that there is a close correlation between the firmness of the flesh of Bartlett pears as measured by the pressure tester, the quality of the ripened product, and the length of time the fruit may be held in storage. The work of these investigators was done primarily with the idea of obtaining the best product from a fresh-fruit standpoint. The recommendations as to time of picking and methods of handling were made so as to secure the best product possible for the fresh-fruit market. However, the application of the same indices to Bartlett pears intended for the cannery has resulted in the question as to whether the same maturity and harvesting recommendations would serve for pears intended for the cannery. Mag-

[4] Information obtained from the State Horticultural Office at Yakima, Wash., and from the Wenatchee Valley Traffic Association, Wenatchee, Wash.

ness (*5*) called attention to the possibility of leaving the pears intended for the cannery on the trees until a more mature stage is reached than is desirable for fresh-fruit shipment, and emphasized the fact that in much of the canned fruit of poor dessert quality this quality is doubtless due to the inferiority of the fruit itself at the time of canning.

This question is of special interest to the grower because of the increased tonnage that may be secured by leaving the fruit on the tree until the lower pressure tests are reached. Since a drop of 1 pound in pressure requires that the fruit be left on the trees approximately 5 to 7 days longer, and during this time, owing to the increase in size (the tonnage increase is approximately 10 percent), it is advantageous for the grower to allow the fruit to remain on the tree and thus secure the additional weight. However, fruit that is allowed to remain on the tree too long tends to break down at the core before it reaches the stage of softness desirable for canning. The maximum length of time for which the fruit can be held in storage is usually of less importance for cannery pears, and so earliness of picking is not a major factor in that respect. The early-picked fruit generally receives no price premium from the canner as is usually the case with fruit shipped to the fresh-fruit market.

The matter of correct harvesting time is of interest not only to the grower but to the canner as well. The latter is concerned not only with the stage of maturity at which the fruit is picked but also with the effect of certain harvesting and handling practices, if such practices affect the final canned product.

Questions of particular interest to the canner at present are as follows: At what stage of maturity should Bartlett pears be picked in order to get the best product? Does cold storage of the fresh fruit alter the quality of the final product? If not, how long can the fresh fruit be stored to increase the operating period or seasonal capacity of the cannery? What effect does delaying at relatively high temperatures before storage have on the fruit when maximum length of storage is not important? What effect do the temperature and humidity of the ripening-room have on the quality of the canned product?

It was with these questions in mind that the experiments herein reported were undertaken. They deal entirely with problems of maturity and handling of the fruit prior to its entry into the preparation and processing rooms of the cannery. For this reason standard cannery practice was followed throughout in the preparation and processing, and conditions were kept as nearly uniform as possible. Therefore, any difference noted in the various lots may be ascribed to the treatment received before entry into the preparation room.

In 1927 at the annual meeting of the Northwest Canners Association, C. B. McCall [5] reported the results of some preliminary experiments carried on cooperatively with the junior writer of this bulletin, on the effect of the maturity and storage on the quality of canned pears. In this report McCall called attention to the need of additional work along this and related lines with the idea of securing a better quality of canned pears through an improvement in the raw

[5] McCALL, C. B. THE PROPER DEGREE OF MATURITY FOR CANNING PEARS. Northwest Canners Assoc. Circ. 394, Feb. 10, 1927. [Mimeographed.]

product. No further experiments were conducted at that time, but during the season of 1929 the present writers resumed the work. A mimeographed preliminary report of the investigations was issued in 1931.[6]

The effects of the various maturity, handling, and storage practices included in this study were checked in two ways, (1) as shown by the chemical and physical properties of the fruit, and (2) as shown in the final canned product. Enough material (a 50-pound lug) was included in each treatment to allow a sample to be taken for chemical analysis at the time of harvesting and again at the end of the treatment (i. e., at the time the fruit was ready for processing) and to permit canning of adequate samples for the subsequent examination of the canned product. The work herein reported was continued through the years 1929, 1930, and 1931.

MATERIAL AND METHODS

SOURCE OF MATERIAL

In order that conditions throughout the investigation might be uniform except for the experimental variations, arrangements were made with the growers before the work was begun, whereby the harvesting of the pears was under the control of a representative of the United States Department of Agriculture. For this purpose two orchards in the Yakima Valley of Washington were selected. One of these was located on a heavy loam soil, and pears taken from it were used throughout the 3 years. Another orchard planted on a gravelly loam was selected for the 1929 work, but was changed in 1930 and 1931 for one on a light sandy loam. In 1931 a third orchard was selected on a medium loam soil, and fruit from this orchard was used exclusively for the short-term (1 to 10 days) storage test, with a maximum storage of 30 days. Representative trees apparently in good vigor and normal as to water supply and similar significant factors were selected. The trees, of full bearing age, bore a good crop of fruit each year, and although the annual tonnage varied, the amount per tree was as good as or better than the average yield of the other trees in the same orchard for that year. Fruit from the two orchards was used throughout the experiments except in the case of the very short storage (1 to 10 days) lots of 1931. This procedure permitted a comparison of the effect of the two soil types as well as a check on the effect of the different precanning treatments.

SELECTION OF MATERIAL

In the preparation of the different lots a composite sample from the different trees was selected. In the earlier pickings the fruit was picked for size, the minimum diameter being 2⅜ inches (no. 1 cannery grade). Thus the earlier pickings served as a means of thinning the fruit, a common practice in the Yakima and Wenatchee districts. With trees used for the experiments this thinning was usually necessary to prevent breaking of the branches. Later in the season all of the fruit was picked from the selected branches, but

[6] EZELL, B. D., and DIEHL, H. C. THE RELATION OF MATURITY AND HANDLING TO QUALITY IN CANNED BARTLETT PEARS. Feb. 1931. [Mimeographed.]

pears taken from branches on several trees were included each time to give a composite sample.

In determining the maturity, 10 representative pears were taken and pressure tests were made on the pared flesh after harvest by means of the United States Department of Agriculture pressure tester, using the $\frac{5}{16}$-inch plunger.

Samples for chemical analysis were also taken from 10 representative fruits. With the aid of a cork borer, a portion of each fruit extending through the short axis and including portions of the blushed and unblushed sides was taken. The skin and core were removed and 100 g of the tissue sliced directly into the beaker containing 100 cc of 95-percent alcohol for preservation. This material was then added to enough boiling alcohol to make a final alcohol concentration of 80 percent, and boiled for 3 minutes. The preserved material was stored in tightly stoppered glass bottles until the final analytical work was done during the following winter.

METHOD OF HANDLING

Throughout the work the treatment of the fruit was uniform except for the particular handling or storage variation to be studied. Cold storage at 30° to 32° F. usually began within 2 or 3 hours after harvest, and there was never a delay of more than half a day at atmospheric temperatures, except for those lots which were ripened immediately or delayed a specified time before storing. When ripened immediately the fruit was placed directly in the ripening room at 70°. When storage of the pears was delayed, the period of delay was calculated from the time at which the fruit for immediate storage arrived at the warehouse. The delayed-storage lots were held at the warehouse at a temperature of approximately 70° until placed in cold storage. The immediate-storage lots were held at 30° to 32° until removed to the ripening room. The ripening-room temperature was about 70° with a relative humidity of 78 to 85 percent except as noted below where the effect of variation in these factors was studied.

Standard cannery procedure was followed in the preparation and processing of the fruit. The experimental lots were placed directly in the cannery line along with fruit being processed commercially at the same time. For analysis of the fruit at harvest the samples were taken within a few hours after the fruit was picked. Samples of the ripened fruit were taken when the fruit was ready for canning, and a uniform stage of ripeness was used as a criterion rather than a uniform period in the ripening room, because of the difference in time required for the various lots to reach a comparable stage of ripeness. Six days in the ripening room was usually sufficient for cold-storage fruit, and the time varied comparatively little with the different lots. Fruit delayed at a temperature around 70° F. before storage required somewhat less time, and fruit ripened without storage required several days longer. Throughout the work, either in canning or in taking samples for chemical analysis, the maturity of the fruit rather than the number of days the fruit had been in the ripening room was taken as a guide.

METHOD OF CHEMICAL ANALYSIS

The samples were prepared for analysis by decanting the alcohol from the preserved material through a weighed filter paper placed inside the extraction thimble. The thimble containing the sample was washed 2 or 3 times with 80-percent alcohol and then transferred to a Soxhlet apparatus and extracted with 80-percent alcohol for 8 hours. In the latter part of the work it was found that by macerating the tissue the extraction period could be reduced to 4 hours. The extract was combined with the preserving fluid made up to definite volume, and aliquot portions were taken for the various determinations.

The determinations made upon the material included total solids, alcohol-soluble and alcohol-insoluble materials, free reducing and total sugars, and total acidity. The alcohol-soluble material was determined by evaporating an aliquot portion of the alcohol extract at 78° C., followed by drying to constant weight in a vacuum oven at 75°. The alcohol-insoluble portion was determined by placing the filter paper and contents in a weighing bottle and drying to constant weight in a vacuum oven. The sum of the two gave the total solids. Free reducing and total sugars were determined from an aliquot portion of the alcoholic extract. The alcohol was driven off over a steam bath, water being added to the aliquot part to prevent caramelization of the sugars. The solution was then cleared with neutral lead acetate made up to volume and filtered. The excess lead was precipitated with sodium oxalate, and the solution was again filtered. This cleared solution was used for the determination of soluble sugars.

The reducing action of the sugar was determined in the 1929 and 1930 samples by heating the copper sulphate alkaline tartrate solution at 80° C. for 30 minutes, as recommended by Quisumbing and Thomas (*11*), and titrating the cuprous oxide with potassium permanganate as specified in the modified Bertrand method as given by Mathews (*8*). With the 1931 samples the Shaffer-Hartmann (*12*) idiometric method of titration was substituted for the permanganate method to determine the cuprous oxide. Preference was given to the Shaffer-Hartmann procedure because of its rapidity and convenience in the local laboratory. Total sugars were determined by hydrolyzing 50 cc of the cleared solution with 5 cc of concentrated hydrochloric acid for 24 hours. This was neutralized with sodium carbonate, made up to volume, filtered, and an aliquot part taken for reduction.

The acid content of the sample was determined by passing a portion of the fresh tissue, selected as noted above, through a Clark sampling press and determining the acid by the official method prescribed by the Association of Official Agricultural Chemists (*1*). The results are expressed as percentage of fresh weight.

The analytical data are given in connection with the different treatments, together with the discussion of the relation of the latter to the canned product.

METHOD OF CANNING

When the fruit reached prime canning condition it was taken to the cannery and prepared according to the standard procedure of

the cannery. From this point the treatment was uniform for all samples. The preparation and canning were usually done by the same persons each time, and the regular routine of the plant was followed, care being taken to prevent delaying the experimental lots longer than absolutely necessary. During the time of preparation the fruit was held in a 3-percent salt solution. It was then washed, sized, and placed in plain no. 2½ cans; 30° Brix sirup was added by hand, and the cans were placed in the regular line for cooking. They were given an exhaust of 7¾ minutes at 190° to 195° F., closed with a Canco closing machine, processed for 15 minutes in a rotary cooker at 211° (boiling water), and thoroughly cooled in running water.

Samples of the canned product were cut and examined at various intervals after canning over a period of a few days to as long as 2 years. In the examination of the material the writers were assisted by representatives of different bureaus in the United States Department of Agriculture, representatives of the National Canners Association, members of the Northwest Canners Association and of the California Canners League, members of the research staff of the leading can companies, practical cannery men, and others qualified to judge processed fruit or horticultural products generally.

POINTS CONSIDERED IN COMPARING THE CANNED PRODUCT

In judging the canned material, color, texture, clearness of the sirup, and flavor were the main factors considered, but no numerical values were assigned to these factors. In commercial practice flavor often receives less weight than the other factors, provided no "off" flavor is present. It has been found that the differences in flavor due to treatment are somewhat masked by the sirup. It was also true that when differences in flavor were evident, personal preference largely determined the selection of the treatment that seemed to give the best flavor. The comparative lack of emphasis on flavor at present, particularly from the wholesale buying standpoint, was shown by the fact that buyers and canners often made their decisions before tasting and seldom changed them afterwards. Consideration was necessarily comparative, each treatment being checked against others in the series. Size and workmanship were not considered in judging this material, as is usually done in judging the canned product, since these were not affected by the factors studied in this bulletin. However, pears of as nearly uniform size as possible were selected each time for comparison, and the workmanship was similar throughout.

The drained weight and sirup cut-out were determined in several cases, but it was found that a slight difference in the size of the pieces or the amount of sirup in the can more than offset any differences due to the treatment.

COLOR

In judging pears, a clear cream-yellow tending toward translucency is desired in the best material. Fruit with a darker color grading toward pale orange-yellow is not considered so desirable. While it is difficult to match the ideal color of canned pears with a standard color

chart, an effort was made to do this. Fruit judged as having the best color corresponded closely to cream color or massicot yellow, plate 16 in Ridgway's color standards,[7] while departures from the ideal often were in the direction of pale orange-yellow, Ridgway's plate 3.

TEXTURE

The texture of canned pears should be tender, the flesh being almost soft enough to fall apart when held at one end and shaken gently, but still firm enough to be cohesive. The pieces should retain their form and not break apart or disintegrate of their own weight.

CLEARNESS OF SIRUP

The sirup should be clear and bright with little sediment. In these studies the principal difference noted in an examination of the sirup was the amount of sediment present, indicating roughly the amount of disintegration which had taken place.

FLAVOR

The flavor apparently most desired in canned Bartlett pears is a moderately sweet, sprightly, slightly aromatic, characteristic Bartlett-pear flavor. It is recognized, of course, that individual tastes vary widely. The conclusions given are based upon the preference of a majority of those tasting the fruit.

EFFECT OF MATURITY

In order to study the effect of maturity on the quality of the canned product, pears were picked at different stages of maturity during the seasons of 1929 and 1930. In 1930 the first fruit was harvested on July 28, when it tested a little above 20 pounds according to the pressure test. Pickings were made at weekly intervals thereafter until September 11, when the fruit tested from 12 to 13 pounds, with a minimum of 7 to 10 pounds. This gave a range of maturity from the time the first Bartlett pears were being picked for fresh shipment until practically all the fruit intended for the cannery had been harvested. The dates of picking and the pressure tests in pounds are given in table 1.

TABLE 1.—*Date of picking and pressure test of Bartlett pears used in the 1930 tests*

Date of picking	Pressure test		Date of picking	Pressure test	
	Pears from heavy soil	Pears from light soil		Pears from heavy soil	Pears from light soil
	Pounds	*Pounds*		*Pounds*	*Pounds*
July 28	20.3	20.2	Aug. 27	15.0	15.0
Aug. 4	18.6	18.7	Sept. 2	14.3	14.6
Aug. 12	17.0	17.0	Sept. 11	12.0	13.0
Aug. 19	16.0	16.5	Do [1]	7.3	10.6

[1] Ripest fruit.

[7] RIDGWAY, R. COLOR STANDARDS AND COLOR NOMENCLATURE. 43 pp., illus. Washington, D.C., 1912.

One cannery lug of the ripest fruit, selected from that picked September 11 from each orchard, was placed in cold storage for 9 days and then removed to the ripening room. This fruit showed a very low pressure test at harvest (7.3 and 10.6 pounds), developed practically 100 percent internal breakdown before reaching the canning stage, and consequently was discarded. The other lots were held for 30 days at 30° to 32° F., ripened, and canned when in the proper condition.

The effect of pear maturity as demonstrated in different ways will be discussed separately for each factor.

ON YIELD IN THE ORCHARD

It has been shown by several investigators (*4*, *9*) that there is an increase in size and therefore in yield of Bartlett pears allowed to remain on the tree after the optimum picking maturity. Murneek (*9*) has shown that there is a close correlation between increase in the transverse diameter and increase in weight. It was found that by taking the transverse diameter and calculating the volume of the fruit by the formula $V=1/6\pi D^3$, as if it were a sphere, the volume was less than that indicated by water displacement. However, if the calculated volume was multiplied by the factor 1.1 the result was very close to the actual volume. This method made possible measurement of the same fruit throughout the season. The percentage increase in size was determined in this manner, and the increase in weight was assumed to be directly proportional, although there is evidence that the specific gravity of pears increases as they become more mature. This would indicate an even greater weight increment in weight than in volume. Hereafter, tonnage may be used in the discussion of yield differences instead of volume or size.

Studies made in this connection during 1930 in the Yakima Valley and in 1932 in the Wenatchee Valley show that this increase in size very materially affects the tonnage that can be harvested. Records were kept on the rate of growth of pears (1) on trees where only one picking was made, and that at the end of the season; (2) on trees where all fruit measuring 2⅜ inches in diameter and larger was removed when the fruit was testing around 18 pounds; and (3) on trees where weekly pickings of the larger fruit were made. Figure 1 shows the rate of growth of fruit remaining on the trees for the different treatments during the 1930 and 1932 seasons. Records were kept in 1930 over a period of 37 days and in 1932 for 18 days. It will be observed that the rate of growth for all treatments was less in 1932 than in 1930. This difference was probably due to the trees having a slightly heavier load of pears in 1932 and to a much larger amount of fruit dropping in 1930, which would serve as additional thinning of the pears for all plots.

Differences in climatic and orchard conditions in the two years doubtless also influenced the rate of growth. It is a general practice to make two or more pickings of cannery pears, the first early in the season serving to thin the crop and lessen the danger of a heavy load breaking the trees. During the 1930 season records were made at weekly intervals from August 5, when the fruit was testing 18.5 pounds, to September 11, when the pressure had dropped to 13

pounds. By correlating the increase in size with the number of tagged fruits dropping in any period, it was possible to determine at what stage of maturity the greatest tonnage could have been harvested. Figure 2 shows the relation between the amount of fruit dropped and the increase in weight of tagged fruit on an unthinned tree throughout the harvest season of 1930.

The average increase in size of fruit per day during the season on the unthinned trees was 1.95 percent. The date of maximum load

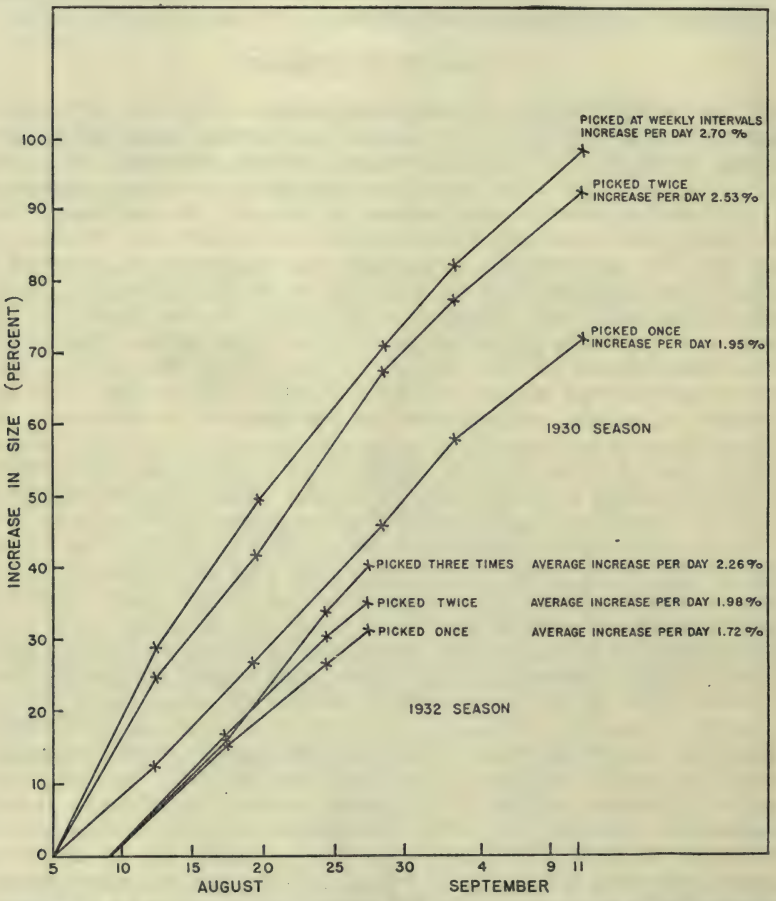

FIGURE 1.—Relationship between number of pickings and rate of growth of pears.

was August 19, when the fruit tested 16.5 pounds; at this time 10 percent of the fruit had dropped. On August 28, 41 percent of the fruit had fallen, but the tonnage had decreased only 19 percent and was still equal to the tonnage of August 5.

When the no. 1 cannery fruit (2⅜ inches in diameter) was removed early in the season the pears showed an average increase in size of 2.53 percent per day. The date of maximum load from this tree, as judged from the tagged fruit, was August 12, when the fruit tested

17 pounds; at this time 14.5 percent of the fruit had fallen. On August 19, 36 percent had fallen and the tonnage had decreased 16 percent. However, the tonnage then remained about the same until August 28, at which time 50 percent of the fruit had dropped. Where the largest fruits were removed at weekly intervals the average increase in size per day was 2.7 percent. The date after which the percentage of dropped fruit was greater than that made up by the increase in size was August 28, at which time the fruit tested 15 pounds. At this date 16 percent of the fruit had fallen. Five days later 36 percent had fallen and the tonnage had decreased 16 percent.

After observing the amount of fruit dropped from other trees in the same block it seemed safe to assume that the rate of dropping was due to natural causes rather than to the experimental treatment.

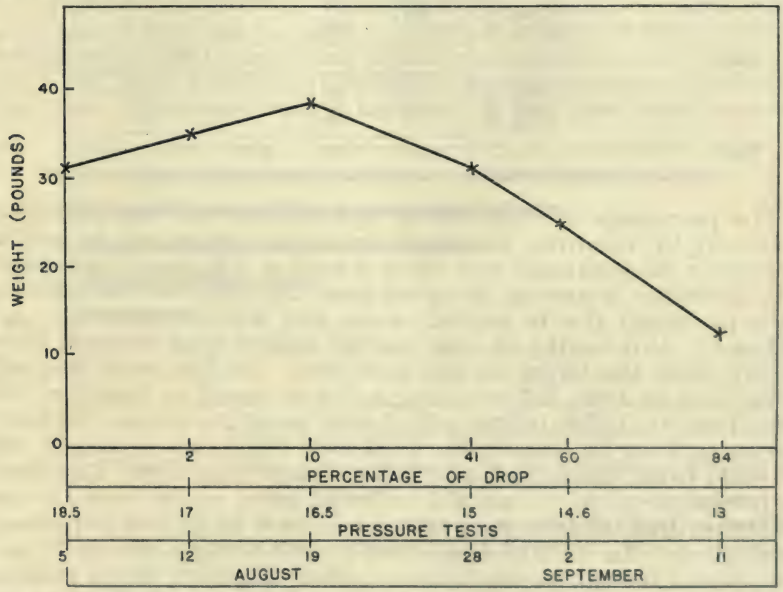

FIGURE 2.—Effect of maturity as measured by pressure tests on increase in size and rate of dropping of pears on the amount of fruit on the tree. (Weight of fruit calculated from diameter measurements of tagged fruit, as explained in the text.)

These results are from trees grown on a light soil. A much smaller percentage of fruit dropped early in the season from trees growing on the heavy soil. In measuring the fruit a certain amount of movement was necessary, which probably caused some of the fruit to drop earlier than it would normally. This would tend to exaggerate slightly the percentage of drop given above.

Work carried on in 1932, with trees on heavy soil, in which records were kept of the total drop from the trees as well as the increase in size of tagged fruits, showed similar results. Records were kept from August 9, when the fruit tested 17.5 pounds, to August 27, when the pressure test was slightly under 14 pounds. Data were secured from trees where 1, 2, and 3 pickings were made. Where 2 pickings were made all fruit 2⅜ inches in diameter or larger was

removed on August 9, 16 percent of the total fruit harvested being removed at that time. Where 3 pickings were made, all fruit 2⅜ inches or larger was removed on August 9 (16.5 percent of the total harvested) and again on August 19 (38.5 percent of the total harvested). Table 2 gives the results of these tests.

TABLE 2.—*Effect of 1, 2, and 3 pickings on fruit remaining on tree*

Pickings		Fruit harvested		Average growth per day	Total growth	Fruit dropped (percentage of total)	Average weight per fruit harvested
Number	Date	Pears	Weight				
		Number	*Pounds*	*Percent*	*Percent*		*Pound*
1	Aug. 27	2,273	913	1.72	34.6	2.9	0.402
2	Aug. 9	345	112				
	Aug. 27	1,561	586				
Total		1,906	698	1.98	39.6	7.0	.366
3	Aug. 9	418	142				
	Aug. 19	985	331				
	Aug. 27	1,113	386				
Total		2,516	859	2.26	46.0	.8	.341

The percentage of culls due to lack of size was not influenced markedly by removing the larger fruits, and amounted to only 2 pounds on the unthinned tree out of a total of 913 pounds harvested. The difference in amount dropping from the different treatments is perhaps largely due to natural causes and without particular significance. It is worthy of note that the smaller fruit dropped more readily than the larger on the same tree. Of 318 pears dropped from trees in 1932, 137 were 2⅜ inches or above in diameter, 134 were from 2⅛ to 2⅜ inches, and 47 were below 2⅛ inches. Of fruit harvested from the same trees, 6,184 were 2⅜ inches or larger, 480 were 2⅛ to 2⅜ inches, and only 31 were below 2⅛ inches. Expressed as percentage of no. 1's, no. 2's, and culls, based on size alone, in the fruit that dropped from the tree, the amount is 43, 42, and 15 percent, respectively. In the harvested fruit the percentages are 92, 7, and 0.5 percent for the corresponding grades. Figure 3 shows graphically the relationship between the size of the tagged fruit on an unthinned tree at the beginning of the 1930 harvest season and the length of time the fruit remained on the tree. The average of all fruits measured on August 5 was 130.9 cc, showing a direct correlation between relative size at the beginning of the season and the length of time the fruit adhered to the tree.

On trees of which records were kept of the total number of pears on the tree, the amount of fruit harvested, and the rate of growth of tagged fruits, it was possible, by assuming the specific gravity of pears to be 1.0 (which is very close to the actual), to compare the actual yield with the estimated yield if 1, 2, or 3 pickings had been made. Assuming the tagged fruit to be representative in size of all the pears on the tree, there were 706 pounds on an unthinned tree on August 9. This weight, with an increase of 1.72 percent per day after the beginning of the harvest (fig. 1, 1932 season) until August 27, should give a yield of 925 pounds; the actual yield,

including 35 pounds of fallen fruit, was 948 pounds. Similarly, on a tree where 2 pickings were made the estimated yield on August 9 was 578 pounds. On that date 112 pounds were harvested. If to this yield is added 59 pounds that dropped from the tree and might be classed as additional thinning, there would be 407 pounds remaining on the tree. An increase of 1.98 percent per day for 18 days would give a yield of 724 pounds. The actual yield, including fallen fruit, was 757 pounds. If only 1 picking had been made, the estimated yield with a 1.72-percent increase per day would have been 755 pounds.

Again, on a tree where pickings were made on August 9, 19, and 27, the actual yield including fallen fruit was 866 pounds, and the estimated yield for 1, 2, and 3 pickings was 893, 875, and 859 pounds, respectively. On three trees where 1, 2, and 3 pickings were made the total actual yield was 2,571 pounds, compared with an estimated yield for the same number of pickings of 2,508 pounds.

While the yield is practically the same whether 1, 2, or 3 pickings are made, other factors may make the greater number of pickings desirable. If all the fruit is harvested at one time there may be

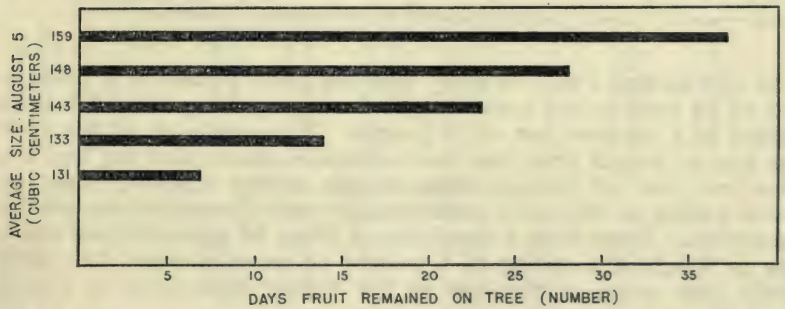

FIGURE 3.—Relationship between size of pear fruit at the beginning of the harvest season and the number of days it remained on the tree.

a wide range in size, some fruits being larger than that most desired for canning. Additional pickings will give a more uniform product of the desirable sizes. Also, if the fruit is not well distributed on the tree and there is danger of limb breakage, or if the tree is overloaded, 2 or more pickings will tend to prevent this breakage.

ON LOSS OF WEIGHT IN THE RIPENING ROOM

In order to determine the effect of maturity on shrinkage, or loss of weight of the fruit while in the ripening room, pears picked at 18 pounds and at 15 pounds pressure test were weighed and ripened under varying conditions. Several small lots consisting of about a dozen representative fruits were used instead of a single large lot. These small lots permitted more accurate weighing, and there was less danger of decay developing and influencing the results. Numerous small lots were used in studying the loss in weight. These studies were made on fruit after a period in cold storage. Table 3 gives the conditions under which the fruit in the two stages of maturity was ripened and the percentage of weight lost in the period

extending from the time of removal from cold storage until the fruit was ready for canning.

TABLE 3.—*Effect of maturity in Bartlett pears on loss in weight during ripening*

Picked at 18 pounds pressure				Picked at 15 pounds pressure			
Lots (number)	Ripening-room conditions		Weight lost	Lots (number)	Ripening-room conditions		Weight lost
	Temperature	Humidity			Temperature	Humidity	
	°F.	Percent	Percent		°F.	Percent	Percent
3	65	80	1.69	3	65	80	1.66
5	65	93	1.24	9	65	93	1.00
3	65	94	1.31	2	65	94	1.09
4	75	70	2.99	4	75	70	2.19
8	75	78	2.10	8	75	78	1.70
4	75	87	2.51	4	75	87	1.74
2	85	68	2.08	4	85	68	1.98
5	85	75	3.30	11	85	75	2.00
4	85	94	1.69	2	85	94	1.42
38 [1]	[2] 75	[2] 82	[2] 2.14	47 [1]	[2] 75	[2] 81	[2] 1.66

[1] Total. [2] Weighted average.

It will be noted that in every case the pears picked at a pressure test of 18 pounds lost more weight during ripening than did those picked at a pressure test of 15 pounds. A comparison of the average loss in weight from the two maturities shows that the less mature fruit lost 29 percent more weight during ripening than did pears picked at the more mature stage and ripened under similar conditions. Even with a humidity of 93 to 94 percent there was a loss in weight amounting to 1 percent or more in every lot. It is likely that much of the loss at the higher humidities is due to respiration in ripening.

ON FRUIT WHILE RIPENING

The fruit from the early-picked lots showed considerable wilting during ripening. Often it failed to develop the uniform bright skin color characteristic of later pickings and showed a distinctly greenish spotted appearance after having been in cold storage 6 weeks or longer, even though ready for canning. The earliest-picked lots never developed the sprightly aromatic flavor characteristic of the Bartlett pear. All through the season it was observed that the immature fruit was not only darker when first peeled but tended to oxidize much more rapidly while being prepared for processing. This was true to such an extent that it was possible to pick out at a distance of several feet and before the fruit was processed the trays containing open cans of immature pears. However, some of the darkening due to oxidation was lost while the fruit was in the exhaust box, so that when the fruit emerged the differences were not so apparent. In pulping the fruit for acid determination, the immature fruit took on a brown color almost immediately, while the more mature pears required several minutes before reaching a color stage comparable to that of the immature fruit at the time pulping was completed. Fruit picked at a pressure test of 14

pounds showed a tendency to break down at the core before reaching a stage of softness desirable for canning. This tendency developed quite rapidly as the pressure test dropped below the 14-pound figure.

ON CHEMICAL COMPOSITION

Table 4 shows the effect of maturity on composition of the fruit. The first series of analyses were made at the time of harvesting. The fruit for the second series was stored at 30° to 32° F. for 30 days after harvest and then ripened at 70° to the most desirable stage for canning. These analyses were made on pears grown on heavy soil. Analyses of fruit from the light soil gave similar results.

TABLE 4.—*Effect of maturity of Bartlett pears on composition at time of harvest and when ripened for canning*[1]

AT HARVEST

Date harvested	Pressure at harvest	Alcohol-insoluble material	Alcohol-soluble material	Total solids	Reducing sugars	Total sugars	Cane sugar	Acid as citric
	Pounds	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
July 28	20.3	4.36	9.84	14.20	5.23	5.94	0.71	
Aug. 4	18.6	4.06	10.21	14.27	5.12	5.94	.82	0.33
Aug. 12	17.0	4.13	9.60	13.73	5.22	5.94	.72	.33
Aug. 19	16.0	4.13	10.38	14.51	5.40	6.69	1.29	.28
Aug. 27	15.0	3.37	10.03	13.40	5.37	7.00	1.63	.31
Sept. 2	14.3	3.27	10.00	13.27	4.87	7.00	2.13	.28
Sept. 11	12.0	2.53	11.32	13.85	4.75	8.21	3.46	.20
Do	[2] 7.3	2.34	12.36	14.70	4.79	9.13	4.34	.15

AFTER RIPENING

July 28	20.3	3.32	11.43	14.75	6.01	7.79	1.78	0.26
Aug. 4	18.6	3.30	11.70	15.00	6.24	8.21	1.97	.34
Aug. 12	17.0	3.16	11.90	15.06	6.02	7.99	1.97	.31
Aug. 19	16.0	3.18	11.45	14.63	5.87	8.30	2.43	.31
Aug. 27	15.0	2.53	11.70	14.23	5.97	8.71	2.74	.28
Sept. 2	14.3	2.43	12.19	14.62	5.73	9.20	3.47	.23
Sept. 11	12.0	2.19	11.84	14.03	5.52	8.98	3.46	.15

[1] Analyses expressed as percentage of fresh weight. [2] Tree-ripe fruit.

An examination of table 4 shows that the stage of maturity at which the fruit was picked exerts a considerable influence on its chemical composition, both at the time of harvest and after the fruit has ripened. As the season advances there is a decrease in the alcohol-insoluble solids and in the acids and reducing sugars and an increase in alcohol-soluble materials, cane sugar, and total sugars. In the ripened fruit, owing to variations in total solids, the increase in the alcohol-soluble materials in terms of fresh weight is not distinctly noticeable; however, the increase is readily shown if calculated as percentage of total solids. In the early-picked fruit the insoluble solids make up 28 to 30 percent of the total solids, dropping in storage and ripening to 22 to 23 percent. In the later-picked fruit insoluble solids amount to only 18 to 20 percent of the total solids, dropping to 15 to 18 percent on ripening. Cane sugar increases both in total amount and in percentage of total sugars. On ripening it increases greatly in the early-picked fruit, but remains about constant in fruit picked near the end of the season. Ripening had but little effect on acid changes, as the acids remained practically

the same after ripening as at harvest. The increased acid content at the higher pressure tests explains the more sprightly acid flavor of the early-picked fruit. From a canner's viewpoint, perhaps the most outstanding effect of maturity on raw material, as shown by the analyses, is the increase in total sugars and the decrease in the alcohol-insoluble materials as the season advances. Apparent increase in sweetness is largely dependent upon these two changes along with changes in astringency and acid content. The increase in sugar adds sweetness directly; the decrease in insoluble solids affects the ease of disintegration of the tissue and the consequent perception of sweetness. While no astringency determinations were made, it is realized that a progressive decrease takes place during ripening, giving the effect of increasing sweetness to the taste.

ON THE CANNED PRODUCT

An examination of the canned product shows that there is a considerable difference in the appearance of the early- and late-picked pears. Fruit picked at the higher pressure tests tended to have a distinctly darker or a pale orange-yellow appearance as compared with the clear translucent cream color of the fruit picked at the more mature stage. There was a gradual improvement in color as maturity advanced, although the differences were not so great in the latter part of the season. Considered as to color alone, the lots picked last were probably the best, judged from the commercial viewpoint. Other factors, such as the prevalence of internal breakdown and the amount of fruit dropped from the trees, prevent the commercial harvesting of pears at such low pressure tests. This color difference was very distinct when the various lots were compared directly, even though the fruit picked at the higher pressure tests might be classed as satisfactory if judged alone.

The differences in dessert quality or taste were not so distinctly noticeable, although most of the persons who examined the canned fruit agreed that there were differences in flavor. The majority opinion was that, in order to get the best flavor, pickings would have to be made a little earlier than the optimum for best color. Fruit from the lots picked very late seemed to have lost some of the sprightly aromatic flavor characteristic of canned Bartlett pears.

In the usual judging of canned pears, color probably has played a more important part than flavor. Since the consumer likewise buys primarily on appearance, the question arises among canners as to the feasibility of developing a more aromatic and sprightly flavor in canned Bartlett pears at the expense of color. Possibly a compromise can be effected by picking the pears at pressures somewhat higher than at present desired for best color, but not so high as to affect the color seriously. Seasonal variations will probably have some effect, since the differences between the different maturities were greater in some seasons than others.

Time of picking has comparatively little influence on color of sirup. The texture of the canned product was perhaps a little more granular and firmer in the late-picked fruit. This firmness was probably due to the character of the fruit at time of canning, since it was difficult to get it to soften properly before internal breakdown took place.

STAGE OF MATURITY FOR BEST RESULTS

From the foregoing data and discussion it is seen that the stage of maturity at which the fruit is picked exerts a marked influence on its yield, behavior, and composition. There is an increase in both total and cane sugars and a decrease in acidity as maturity advances. The canned product has a better color and the raw material is oxidized less rapidly during preparation and canning when the fruit is more mature. There is also less loss of moisture in ripening, and the increase in weight during the season while the fruit is on the tree is approximately 2 percent per day.

The fruit picked at a pressure test of from 17 to 15 pounds seemed most desirable, when everything was considered. At these pressures there may be some dropping of the fruit, and growers may insist on picking earlier. However, unless the dropping amounts to about 2 percent per day the increase in size of the pears remaining on the tree will probably make up the difference. The pressure tests indicated above as the most satisfactory will ordinarily permit the harvesting of a maximum tonnage.

EFFECT OF COLD STORAGE

For the cold-storage experiment, pears were picked at the pressure tests given in table 1 and stored at 30° to 32° F. for varying lengths of time. In 1929 and 1930, aside from fruit ripened immediately after harvest, the storage periods ranged from a minimum of 30 days with removal at 10-day intervals up to a maximum storage of 90 days. In 1931 the period of storage was reduced to a maximum of 30 days and shorter periods of storage were also used.

ON FRUIT WHILE RIPENING

A general examination of the fruit after ripening showed that prior storage at 30° to 32° F. caused it to ripen much more uniformly when placed in the ripening room. Fruit ripened immediately after harvest usually has to be sorted once, and sometimes twice or more, in order to use the fruit at the best canning stage. Fruit that has been in cold storage ripens quite uniformly, at least that grown in the arid sections of the Pacific Northwest, so that it is seldom necessary to do any sorting unless lots of well-matured fruit are mixed with lots less mature or with fruit subjected to different handling practices. Even then, sorting by lugs is usually sufficient. This fact is of value in three respects: (1) Less handling of the fruit is required, and a consequent saving in labor is effected; (2) there is less loss from bruising, owing to less handling of ripening fruit; and (3) a more uniform product is provided, since in hand sorting there is always some question among the sorters as to whether particular fruits should be canned immediately, even though slightly green, or should be left until later, when they may be slightly overripe.

It is quite possible that some of the improvement in texture in the stored lots was due to the more uniform ripening, so that as a consequence the fruit could be canned at the time when a large percentage of the individual pears was at the optimum canning stage.

While precooling and very short periods of cold storage (1 to 10 days) were not so effective in improving the quality of the canned product as longer periods in storage, they were of value in causing the fruit to ripen more uniformly, provided the period of storage was sufficient to bring the fruit to a uniform temperature of 30° to 32° F. Pears picked at a pressure test above 18 pounds and held over 60 days in cold storage tended to wilt when placed in the ripening room. This fruit also failed to develop a desirable golden-yellow color and had a distinctly greenish tinge. The flesh of the immature long-stored fruit was not only darker when first peeled but darkened much more rapidly in the preparation for canning.

Eggs of the codling moth are frequently present on Bartlett pears when they are harvested. If the pears are ripened immediately the eggs hatch and the larvae enter the fruit. As a result, fruit that is practically free from worms, or at most 3 or 4 percent wormy at time of harvest, may be 15 to 20 percent or more wormy when ready for canning. Newcomer (*10*) studied the effects of cold-storage temperatures for short periods of time on codling-moth eggs. The maximum time of treatment was 5 days, during which approximately 50 percent of the eggs were killed. He states that the fruit would probably have to remain at 30° F. for at least 10 days or 2 weeks in order to kill all the eggs. A cold-storage period of 15 to 30 days would therefore be beneficial in reducing loss from this source.

ON CHEMICAL COMPOSITION

Table 5 shows results typical of analyses made of the ripened fruit after varying periods in cold storage.

TABLE 5.—*Effect of cold storage for different periods on chemical composition of Bartlett pears when ready for canning*[1]

Stored at 32° F. (days)	Alcohol-insoluble material	Alcohol-soluble material	Total solids	Reducing sugars	Total sugars	Cane sugar	Acid as citric
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
FRUIT PICKED AT 18.5 POUNDS PRESSURE							
0	3.63	12.80	16.43	7.15	8.10	0.95	0.33
40	3.02	11.28	14.30	6.12	7.76	1.64	.28
50	3.57	11.32	14.89	6.22	7.41	1.19	.33
74	3.11	12.33	15.44	6.67	8.60	1.93	.31
82	3.47	11.98	15.45	6.39	8.29	1.90	.26
90	3.40	12.20	15.60	6.36	8.30	1.94	.20
FRUIT PICKED AT 16 POUNDS PRESSURE							
0	3.07	10.09	13.16	6.52	7.72	1.20	
Precooled to 30° F. overnight	2.97	9.86	12.83	5.80	7.20	1.40	
15	2.99	10.25	13.24	5.73	7.58	1.85	
30	3.13	10.53	13.66	5.95	7.72	1.77	
FRUIT PICKED AT 15 POUNDS PRESSURE							
0	2.19	11.71	13.90	6.54	8.56	2.02	0.36
43	2.53	11.70	14.23	5.97	8.71	2.74	.28
51	2.48	12.07	14.55	6.33	8.86	2.53	.28
59	2.80	11.52	14.32	6.25	8.73	2.48	.28
67	2.56	11.63	14.19	6.02	8.60	2.58	.26
81	2.46	11.26	13.72	5.96	8.49	2.53	.23

[1] Analyses expressed as percentage of fresh weight.

The amount of cane sugar in the pears increases and the acid decreases if the fruit is placed in cold storage. This increase in cane sugar is very pronounced in fruit picked at higher pressure tests, and is also greater in the later picked lots. It has but little influence, however, on total sugars in pears. The acids decrease in storage. By comparing the acid changes in fruit stored at 30° to 32° F. then ripened at 70° (table 5) with those ripened immediately after harvest (table 4) it is seen that long storage is more effective in lowering the acid content than is ripening at 70°. Differences in the other constituents are comparatively negligible. Because of the differences observed in the texture of the canned product from the stored lots (as noted below), it was expected that there would be a difference in the alcohol-insoluble material found in these lots. However, analyses that showed this was true in only a small number of cases.

In 1931 the period of storage was reduced to a maximum of 30 days, since it was shown in the earlier work that pears in cold storage for 30 days gave a better canned product than either fruit ripened immediately or that held in storage for longer periods. Fruit was picked at a pressure test of 15, 16, and 17 pounds and held in cold storage for varyling lengths of time up to a maximum of 30 days, in order to determine the minimum time necessary to secure the benefits of cold storage. The periods in storage were precooling overnight to a fruit temperature of 30° F. and storage for 1, 2, 4, 6, 10, 15, 20, or 30 days. Chemical analyses were made on fruit which was ripened immediately, precooled overnight to 30°, and stored for 15 days and for 30 days. Results of analyses on the fruit picked at 16 pounds are given in table 5 and are typical of results from fruit harvested at other pressures.

An examination of these analyses shows that the factors affected by cold storage over long periods are similarly affected by precooling overnight, but to a lesser degree. A 15-day storage period seems to be as effective as a longer period.

ON THE CANNED PRODUCT

Bartlett pears that have been held in cold storage seem to have a better color and texture when subsequently canned than fruit ripened and canned immediately after harvest. With a range of storage periods from 0 to 90 days at 30° to 32° F., the best canned fruit was obtained from the lots that had been in storage from 15 to 30 days. Fruit stored for either shorter or longer periods was less desirable. A shorter period failed to give the full benefit of cold storage, and longer periods brought on additional complications.

Fruit ripened immediately after harvest had a poorer texture, which may best be characterized as lacking in cohesion and firmness. It was also of a darker, less desirable color and did not seem to have so desirable a flavor. The effect of precooling or storage for less than 10 days was not distinctly noticeable on the canned product, although after 3 or 4 days there seemed to be a slight improvement in texture, indicating that this quality is more readily influenced by short periods of cold storage than is color. Storage for 15 days apparently was as effective as longer periods, since there was little differ-

ence between the 15-day and the 30-day lots. Longer periods caused a gradual darkening of color, although at 40 to 45 days it was only slightly noticeable and at 50 to 60 days there was a resemblance to the color of canned pears made from fruit ripened as soon as picked. Storage for longer than 60 days cannot be recommended because the color of the canned product tended to darken rapidly when this period was exceeded. The pears stored for very long periods tended to be more granular in texture and to have lost much of the melting, buttery consistency in the flesh, characteristic of pears of the intermediate stored lots. The darkening of color was especially noticeable in fruit picked at the higher pressure tests and gradually decreased in the more mature fruit. At 14 pounds and below there was but little difference in the intermediate and long storage lots insofar as color was concerned.

Cold storage of the fruit will be advantageous to canners also, because they may thus prolong the canning season without loss of quality in the finished product. For fruit that could be processed during the harvest season it may mean an additional expense. However, since advantages other than an improved product result from cold storage, such as a saving in labor due to more uniform ripening and reduced losses from bruising and "pinworms", these savings will act to reduce or offset the initial cost of storage. In some cases these economies may more than equal the cost of storage.

EFFECT OF HOLDING AT HIGH TEMPERATURES BEFORE COLD STORAGE

Bartlett pears held for 2, 4, and 6 days after picking before cold storage, at the high atmospheric temperatures prevailing during the pear harvest, were less satisfactory when ripened than fruit stored immediately after harvest. The chemical composition of the delayed lots at the time of canning was very irregular and no definite conclusion could be drawn from the analyses. There was a tendency for the total sugars and the cane sugar to be less in the delayed-storage lots, but this was not true in all cases. Fruit held for 4 or 6 days at high temperatures sometimes completed the ripening process within 30 days in cold storage at 30° to 32° F., with a resultant loss by decay and a poor texture in the canned product. Fruit delayed 4 days and then stored at 40° was a total loss from scald and break-down within 30 days. The fruit placed in cold storage immediately after harvest gave the best canned product, in both quality and appearance, with a gradual deterioration in these factors proportional to the time for which the fruit was delayed before storage.

EFFECT OF RIPENING-ROOM TEMPERATURES AND HUMIDITIES

To test the effect of ripening-room temperatures and humidities on the quality of the canned product, Bartlett pears were ripened at 60° to 65° F. and 80° to 85° and at relative humidities of 70 and 90 to 95 percent. Similar fruit ripened at 70° with a relative humidity of 78 to 85 percent was used as a check for comparison in judging the canned product. Table 6 gives analyses typical of those made on fruit ripened at the two temperatures, that held at the

higher showing an increase in the alcohol-soluble material and reducing sugars and a slight increase in the total sugars.

TABLE 6.—*Analyses of Bartlett pears ripened at 65° and at 85° F.*[1]

Ripening-room temperature (° F.)	Alcohol-insoluble material	Alcohol-soluble material	Total solids	Reducing sugars	Total sugars	Cane sugar	Acid as citric
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
65	3.08	11.27	14.35	6.38	9.51	3.13	0.28
85	2.99	11.99	14.98	6.98	9.65	2.67	.28

[1] Analyses expressed as percentage of fresh weight.

Two lots of fruit were held for 30 days after harvest at 90° F. and a relative humidity of 90 percent. At the end of that time the fruit was still hard and tough, and it failed to ripen satisfactorily when removed to a lower temperature. This is in agreement with results reported by Shamel (*13*) and Taylor and Overholser (*14*) on the effect of high temperatures in ripening Bartlett pears. They found that storage at temperatures above 85° retarded ripening.

An examination of the canned product indicated that fruit ripened at 70° to 75° F. gave a product as good as or better than fruit ripened at either a higher or a lower temperature. Fruit ripened at 60° to 65° was slightly darker in color than that ripened at 70° to 75°. Fruit ripened at 80° to 85° was slightly slower in ripening, and that ripened at 90° was very markedly slower.

Fruit held for 3 days after harvest at 90° F. and then ripened at 70° to 75° had an objectionable chalky appearance around the core. Fruit held for 3 days at 90° and then stored at 30° to 32° did not have the chalky appearance, but was not as desirable as that given immediate storage. It was also observed that a greater loss of weight occurred during ripening at the higher temperatures.

Humidity is of importance in the ripening room, and where there are special rooms for ripening the fruit for canning, this factor seems to take care of itself very well, since considerable water is given off by the fruit in ripening. Special precautions will probably be necessary only where fruit is placed in an open shed for ripening. Low humidity will cause some wilting during ripening, but small losses of weight may not be serious and may even have an advantage in that the subsequent siruping and processing may permit recovery of some of the weight lost and may allow expansion to take place during the exhausting and cooking, resulting in a better texture of the canned product.

Fruit ripened at very high humidities loses comparatively little weight in ripening, and the flesh is firm and juicy. However, during the steam exhaust of the product the outside cells completely filled with juice are often ruptured, giving a slightly ragged appearance to the fruit and increased cloudiness in the sirup.

Table 7 shows the effect of humidity on the loss of weight during ripening. These lots include fruit picked at pressure tests of 18 and 15 pounds.

TABLE 7.—*Effect of humidity on loss of weight of Bartlett pears during ripening*

Low-humidity storage				Medium-humidity storage				High-humidity storage			
Lots	Ripening conditions		Loss of weight	Lots	Ripening conditions		Loss of weight	Lots	Ripening conditions		Loss of weight
	Temperature	Humidity			Temperature	Humidity			Temperature	Humidity	
Number	° *F.*	*Percent*	*Percent*	*Number*	° *F.*	*Percent*	*Percent*	*Number*	° *F.*	*Percent*	*Percent*
2	85	68	2.08	8	75	78	2.10	4	85	94	1.69
4	85	68	1.98	8	75	78	1.70	2	85	94	1.42
5	85	75	3.30	3	65	80	1.70	4	75	87	2.51
11	85	75	2.00	3	65	80	1.66	4	75	87	1.74
4	75	70	2.99					3	65	94	1.31
4	75	70	2.19					2	65	94	1.09
								5	65	93	1.24
								9	65	93	1.89
[1] 30	[2] 82	[2] 72	[2] 2.38	[1] 22	[2] 72	[2] 79	[2] 1.84	[1] 33	[2] 71	[2] 92	[2] 1.69

[1] Total.
[2] Weighted average.

In some years pear canners experience considerable difficulty because the stems [8] of the fruit turn yellow or brown after canning. Many canners now remove the stem, and of course where this is done there is no problem. A slight yellowing of the stems was noted in some of the writers' experimental lots, but it was impossible to connect its appearance with maturity, handling, or storage treatment. Neither freezing of the fruit in storage nor deliberate change of acidity at time of canning seemed to influence this yellowing.

EFFECT OF SOIL TYPES

Soil types apparently play a minor role in pear growing insofar as the canned product is concerned. So long as normal growing conditions prevail with reference to water supply, soil fertility, and similar factors, and the crop quality is comparable, there is probably no appreciable commercial difference in the quality of the canned product. In 1929 fruit from the heavy soil gave a slightly better product; in 1930 the reverse was probably true, and in 1931 there was no apparent difference. Where differences due to soil types were noticeable after canning, the orchard that produced the best pears as judged by the fresh fruit also gave the best product when canned.

SUMMARY

The experimental work described herein has been concerned with the effect of maturity, handling, and storage of Bartlett pears on the quality of the canned product. The phases studied were those that take place prior to the entry of the fruit into the preparation or canning room. In the preparation and processing, standard cannery procedure was followed, and methods were made as nearly uniform as possible throughout. Chemical analyses were made at

[8] Stem, as used in this discussion of the canned product, refers to the prominent vascular tissue between the external stem and the carpels or seed cavities of the pear.

harvest and again when the fruit was ready for canning. The work extended over a period of more than 3 years.

Bartlett pears were picked at pressure tests ranging from 20 to 7 pounds (using the U. S. Department of Agriculture tester with the $\frac{5}{16}$-inch plunger and with the skin removed), and covered a period extending from the time when the first fruits were picked for commercial fresh shipments to the time when the last commercial pickings were made for the cannery.

Bartlett pears in the Yakima and Wenatchee Valleys increased in size from 1¾ to 2 percent per day throughout the season. If the percentage of fruit dropping from the trees was less than this figure, the increase in size balanced the loss from dropping. The pressures recommended will normally permit a maximum tonnage to be harvested.

Fruit picked at the higher pressure tests tended to lose weight more rapidly in the ripening room than that picked at the lower pressure tests, and often wilted noticeably.

Pears intended for the cannery gave the best finished product when the fruit was harvested at a pressure test of from 17 to 15 pounds. Fruit picked at a higher pressure test was generally darker when cut and became more so during preparation for canning. At pressure tests much below this range there was some loss from internal break-down by the time the fruit reached the canning stage, and the amount increased rapidly as the pressure dropped.

Pears held for a period of 15 to 30 days in cold storage had a better color and texture when canned than either those ripened without storage or those stored for longer periods. However, fruit harvested at the pressure tests from 17 to 15 pounds gave a fairly good product, even when stored for 2 months before canning.

Pears placed in cold storage at 30° to 32° F. immediately after harvest were better colored when canned and showed less loss from break-down and decay than the fruit delayed for 2, 4, or 6 days at higher temperatures before placing in cold storage.

A ripening temperature of 70° to 75° F. gave the most rapid and uniform ripening and resulted in the best canned product. A relative humidity of 78 to 85 percent in the ripening room gave satisfactory results.

Soil types had no appreciable effect upon the quality of the canned product, provided normal growing conditions prevailed.

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STORAGE OF MILL CANE

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INTRODUCTION

Rainy weather always has been a limiting factor in the harvesting of sugarcane in Louisiana. The gummy clay soils, when wet, make the passage of wagons and cane loaders in the fields difficult and sometimes impossible. During rainy weather the roads in the fields are soon cut into deep ruts and mudholes, making transportation of cane laborious and often impracticable for days at a time. Any prolonged interruption of harvesting and transportation of cane leads to the operation of mills at reduced capacity or to actual suspension of mill operations, resulting in prolonging the grinding season and increasing the cost of production of sugar.

The data [1] in table 1 give the percentage loss of factory time during the grinding season, resulting from a shortage of cane, due to rain, in 11 factories distributed over the Cane Belt, for the year 1932, and in addition, for 5 of these factories for 1931, and for 1 of them for 1930, 1931, and 1932. It is believed that these percentages are fairly representative of the normal loss of factory time in Louisiana. One factory reported that the loss during 1932 was less than normal. Another factory reported an average loss of 18 percent for 30 years.

[1] Furnished by officials of the various cane-sugar factories.

TABLE 1.—*Loss of factory time resulting from the shortage of cane due to rain*

Factory	Year	Loss of time	Factory	Year	Loss of time	Factory	Year	Loss of time
		Percent			*Percent*			*Percent*
A	1930	18	D	1932	29	I	1931	12
	1931	21	E	1932	15		1932	4
	1932	16	F	1932	18	J	1931	17
B	1932	31	G	1932	13		1932	7
C	1932	12	H	1931	18	K	1931	15
				1932	9		1932	7

The economic importance of this loss in time becomes evident when the following facts are considered: (1) The percentages given in table 1 represent over a million tons of cane; (2) the cane must be ground in a limited grinding season from about October 10 to 20 to January 1 to 10 (usually from 60 to 90 days), the beginning of the season being determined by the maturity of the cane and the end by the increasing freezing hazard with the advance of the season; (3) any prolongation of the grinding season, aside from increasing the cost of sugar manufacture, directly increases the freezing risk.

Considering the expensive equipment, the large personnel required for the milling of cane, the relatively short time during the year that cane can be ground, and the possible loss of cane due to freezing, the loss of time becomes the source of enormous yearly financial losses. A single example of the cost of such loss of time to a factory with an annual crop of about 120,000 tons will serve to make these losses more concrete. On the basis of an average yearly loss of time of 18 percent it was estimated by the management of this factory that by providing facilities for properly storing sufficient cane to insure continuous milling a saving of over $100,000 a year would be realized from factory and field operations.

As a result of the adverse economic conditions of recent years considerable interest has been stimulated among planters in the devising of means to reduce the cost of field and factory operations. This interest has extended to the possibility of developing methods of storing cane economically during fair weather to insure continuous factory operations. Because of the cheapness of cane and the enormous volume required for mill operations any system of storing mill cane must be, of necessity, relatively simple and cheap. A number of methods of storing cane have been under consideration, but the one which appeared to be the most practical from the standpoint of costs and effectiveness was that of sprinkling the cane after it had been accumulated in large piles placed in the open or under shade.

REVIEW OF THE LITERATURE

There has been an enormous amount of experimental work done on loss of sucrose in harvested cane. The environmental conditions under which these experiments were conducted, the methods of approach, the varieties, character, and amount of cane used, the time interval between analyses, the total duration of the experiments, and

the avowed objective to be attained varied greatly. In some cases (*6, 11, 15, 18, 20*) [2] an attempt has been made to state definitely some of the environmental conditions of the experiments, but in those cases the information given is inadequate to an effective analysis of the part a particular phase (temperature, humidity, air movement, etc.) of environment plays in the loss of sucrose. In no case have the environmental factors been controlled and definitely isolated. Some of the experiments (*4, 10, 11, 12*) have been directed toward practical methods of preventing deterioration, but storage experiments have not been carried to a successful practical conclusion on a large scale. In most cases when cane has been kept wet by sprinkling or other means there is general agreement (*4, 10, 11, 12, 22*) that deterioration is retarded, but there are exceptions (*12, 20*). There is general agreement that cane stored in the shade shows less deterioration than cane stored in the sun (*12, 16, 17, 18, 19, 20*), although again there are exceptions (*16*). Some attempts have been made to study the effect of temperature on the rate of deterioration, but the simultaneous effect of air humidity was not taken into consideration (*6, 20*). It has been quite clearly shown that there are varietal differences in susceptibility to deterioration (*5, 7, 10, 15, 16, 17*), although the varieties studied differed and were limited to commercial varieties grown in the country in which the work was done. A recent paper (*14*) reports that under the same conditions varieties showing the greater loss of moisture show the greater rate of deterioration, but neither earlier work (*11*) nor that of the writers supports this claim.

PLAN OF EXPERIMENTS

Because of the apparently conflicting views held by previous investigators and the absence of more exact knowledge regarding the causes of deterioration, it has been found necessary by the writers to undertake a systematic study of the factors involved in deterioration.[3] As a result of this study, it is believed that a practical method of storing mill cane in Louisiana has been found that should insure more continuous factory operation. The phase of this study to be reported in this bulletin deals principally with the effect of sprinkling and of the absence of sprinkling on the composition of (1) mill cane stored in small piles of varying sizes in the shade as well as in the open, and (2) mill cane stored in large piles (7 to 260 tons) in the open, but consideration is also given to the weather conditions prevailing during the experiments and the temperatures existing in piled cane. Some data showing the relationship between weight changes (moisture change) and deterioration in stripped and unstripped cane are presented, since, too, such a relationship has a very important bearing on the problem of handling and storing sugarcane.

VARIETIES OF SUGARCANE USED

The following varieties of sugarcane were used: During 1930, P.O.J. 36–M, P.O.J. 213, and Co. 281; during 1931, P.O.J. 234, P.O.J. 213, P.O.J. 36–M, Co. 281, and C.P. 807; during 1932, P.O.J.

[2] Italic numbers in parentheses refer to Literature Cited, p. 28.

[3] Deterioration as used in this bulletin refers to the loss of sucrose by inversion, as it will be shown that inversion is the primary chemical change taking place in sound harvested cane.

213, P.O.J. 36–M, and Co. 290; and during 1933, P.O.J. 36–M, Co. 281, and C.P. 28/19.

STORAGE FACILITIES

To provide shade a shed 10 by 20 feet and 8 feet high in front and 6 feet high in the rear was erected, facing north. The roof proper extended 8 inches beyond the limits of the building in all directions. Further to protect the cane against rain and sun there was an extension of the roof in the front and back of 3.5 feet. These extensions had considerable slope downward. The shed was divided in half by a solid lumber partition. The ends of the shed were boarded up. Each half of the shed was divided into three 35-inch sections separated by 2- by 4-inch studdings set 2 feet apart. The sections were provided with a false floor made from 2- by 4-inch lumber, 2 feet apart, and 6 to 8 inches above the ground.

For the storage in the open, six racks were constructed of 2- by 4-inch lumber. The racks were of the same dimensions as the sections in the shed and were similarly constructed. The racks were so placed in a field south of the shed that the sun had full play on each of them. These facilities were used in connection with the storage of cane in small piles.

When larger piles of cane were used, the cane was stored in the mill yard of a plantation adjacent to the United States Sugar Plant Field Station. The piles were sufficiently far apart so that the shade of one pile did not fall on the other.

SAMPLING

SMALL PILES

In all the experiments except one conducted during 1933, to be discussed later, the cane of a given variety from a plot of cane of fairly uniform composition was transported to the shed promptly after cutting and placed in a large pile. In order to insure comparable composition of the cane in all lots stored, units of 4 or 5 stalks of cane were taken from the pile at one time and placed successively in a section (or rack) of each half of the shed and in two racks in the open [4] (when cane was simultaneously stored in the open), until about 1,500 to 1,800 pounds were stored in each rack. The cane was piled with the butts in the same direction in all cases. Five 30- to 40-stalk samples were used for each analysis. In the case of the original or check samples each sample was selected at random from the entire lot of cane. In each successive sampling five samples were selected from each rack by taking stalks at random over the entire pile. The surface moisture on the samples of sprinkled cane was allowed to dry off spontaneously before the cane was ground and analyzed.

LARGE PILES

Four experiments were conducted during three seasons (1930, 1931, and 1932) in which piles of cane (P.O.J. 213) ranged from 7 to 70 tons. Two piles were used in each experiment, one of which was sprinkled and one left unsprinkled. An effort was made to make the cane of the two piles as comparable as possible in sucrose content and purity. A given area of cane was selected in the field, cut, and hauled to the mill yard in trucks containing from 5,000 to 7,000 pounds each.

[4] During the season of 1931 and in one experiment during 1932 and 1933 cane was stored in the open.

The cane taken from the trucks was alternately placed on the sprinkled and unsprinkled piles. As long as the piles are relatively small it is possible to obtain cane of fairly uniform composition. As the size of the pile increases the uniformity decreases because of the variability in composition of the cane from a larger area.[5] This method of sampling not only involves the uncertainty of obtaining similar cane in the two piles, but affords no opportunity of knowing the condition of the cane when stored.

In one of the experiments, factory-mill analysis alone was employed; in two other experiments, the factory-mill analysis was supplemented by hand-mill samples of known composition which were placed at the center and on the top of the piles, and in the fourth experiment hand-mill samples only were used. These hand-mill samples were selected at the time the piles were being made from a given quantity of uniform cane and consisted of 30 to 50 stalks which were drawn at random from a given portion of a heap row. The number of samples used in a given analysis varied from 2 to 5. When the smaller number was used the samples consisted of 50 stalks. Analyses were made at the beginning of storage; at intervals, in the case of samples stored on top of the piles; and at the end of storage, in the case of samples stored on top and at the center of the piles. This method of sampling made it possible to determine the amount and the progress of deterioration.

During 1933 a single pile of 260 tons of cane was stored in a mill yard and sprinkled during 10 days. No effort was made to control the composition of the pile. Hand-mill samples of P.O.J. 36–M, selected in the same fashion as in the preceding experiments, were used to study the course of deterioration.

SPRINKLING

In the small-pile experiments the cane in one half of the shed was sprinkled and in the other half left dry, and when cane was stored in racks in the open, one lot of each variety was sprinkled and the other left unsprinkled. During 1930, the sprinkling of small piles was continuous. In the one experiment conducted during 1930 with large piles, sprinkling was continuous during the daytime, there being no sprinkling done at night. During 1931, the cane in small and large piles was sprinkled during the daytime at 7, 9, and 11 a.m. and 1, 3, and 5 p.m. The cane was sprinkled only long enough each time to insure wetting all of it. The sprinkling schedule during 1932 was the same as in 1931, except that the 7 a.m. sprinkling was omitted. The sprinkling schedule for the small piles was the same in 1933 as in 1931, and in the case of the large pile it was 8:30 and 10:30 a.m. and 1:30 and 4:30 p.m. daily.

METHODS OF ANALYSIS

In this study, in which it was desired to follow the principal chemical changes which take place in sugarcane stored under various conditions, the analyses were confined to the juice which was expressed by a motor-driven three-roller mill adjusted to give an extraction of approximately 60 percent. It is realized that further tests should be

[5] Factory-mill analyses were made of the entire pile at the end of the storage period in most instances; that is, a continuous fraction of the juice was taken from below the first crusher throughout the grinding of the pile from which the final sample of juice for analyses was taken.

made to determine the composition of the whole cane in order that the actual quantity of sugars lost by respiration and other causes may be calculated.

The juice from each sample of cane was separately collected and weighed. One portion of juice was analyzed for its Brix reading, apparent sucrose, and apparent purity, by the customary methods.[6] Where a detailed analysis [7] was made, equal portions of juice (by volume) were taken from the 2 or 5 replicated samples of cane and combined. The composite samples of juice were centrifuged in a solid-wall basket under standardized conditions as regards speed and time and were then strained through a 200-mesh screen before the analysis was made. This operation removed such extraneous material as bits of cell tissues, wax, and soil particles, which it was believed should not be included in the samples when studying the composition of the juice phase.

The following determinations were made on the composite juice samples: Acidity, pH, sucrose, reducing sugars, dry substance, true purity, ash, and organic nonsugars.

Acidity.—The usual sugar-house method of determining acidity was employed in 1931 and 1932, namely, by titrating 10 cc of juice with 0.1 normal sodium hydroxide solution, with phenolphthalein as the indicator. The samples in 1933 were titrated electrometrically by means of the quinhydrone electrode: 50 cc of juice was titrated to a pH of 7.0 with 0.1 normal sodium hydroxide and the result was expressed as the number of cubic centimeters of alkali required for 10 cc of juice.

pH.—The pH of the juice was determined electrometrically by means of the quinhydrone electrode against a saturated calomel electrode (*13*).

Sucrose.—The double polarization method, with invertase as the hydrolytic agent, in accordance with the official method of the Association of Official Agricultural Chemists (*3, p. 370*), was used in determining sucrose. Initial solution contained 78 g of juice per 100 cc; dry basic lead acetate (Horne's) was used as the clarification agent and anhydrous Na_2CO_3 as the deleading agent. Deleading was controlled very satisfactorily by means of bromthymol-blue paper; the end reaction was taken at the approximate neutral point to this indicator paper. The data are expressed as percentage sucrose on dry substance, i.e., true purity.

Reducing sugars.—In the samples analyzed during the 1931 season, reducing sugars were determined by the Herzfeld method (*3, p. 382; 21, p. 240*) by means of the Meissl-Hiller factors; the samples during the 1932 and 1933 seasons were analyzed by the titration method of Lane and Eynon (*3, p. 377; 21, p. 250*). The latter method was found to be preferable. The burette was jacketed and equipped with an offset outlet, features which were found to be of great value in obviating heating of the reserve sugar solution during the titration. Clarification of the solutions of juice was effected in 1931 by filtration with the aid of diatomaceous earth, and in 1932 and 1933 by neutral lead acetate, while deleading with a dry mixture composed of 3 parts of sodium oxalate and 7 parts of potassium dihydrogen phosphate. A dry deleading agent of this character is to be preferred to a solution of an oxalate and phosphate, as is recommended by Cook and McAllep (*9*) and adopted officially by the Association of Hawaiian Sugar Technologists (*2*), as it obviates aliquoting and the introduction of a dilution factor. The results in this bulletin are expressed as percentage invert sugar based on dry substance.

Dry substance.—The dry substance of the juice was determined according to the official method of the Association of Official Agricultural Chemists (*3, p. 364*), by drying 8 g of juice (10 cc of a solution of juice containing 80 g of juice made to 100 cc) on silica sand at 70° C. in a vacuum (approximately 27 inches).

Ash.—The ash was determined in the 1931 and 1932 samples by direct incineration of 20 g of juice at low red heat; in the 1933 samples the sulphate ash was

[6] These analyses were performed by R. B. Bisland, of the Division of Sugar Plant Investigations, Bureau of Plant Industry, U.S. Department of Agriculture, at the Sugar Plant Field Station, Houma, La., to whom the writers are indebted.

[7] Detailed analyses were limited to the experiments conducted during 1931, 1932, and 1933. In some of the experiments during these years it was necessary to omit detailed analyses and in others to limit them to certain intervals of storage.

determined, but corrected by applying the usual factor of 10 percent. Results are based on dry substance.

Organic nonsugars.—The organic nonsugars were determined by subtracting the sum of the total sugars and ash (moisture-free percentage basis) from 100. Obviously this determination can be given but little emphasis, since it involves the accumulated errors of four other determinations.

EXPERIMENTAL DATA

STORAGE IN SMALL PILES

During 1930 two experiments, one following the other, were conducted in which three varieties (Co. 281, P.O.J. 213, and P.O.J. 36–M) were stored in the shade. One lot of each variety in each experiment was sprinkled and one lot left unsprinkled. Two experiments were run during 1931 in which cane of a given variety was stored in the open and in the shade. One lot in the shade and one in the open were sprinkled and one lot in each case left unsprinkled. Co. 281, C.P. 807, and P.O.J. 36–M were used in the first experiment and Co. 281, P.O.J. 234, and P.O.J. 36–M in the second. In 1 of the 2 experiments conducted during 1932, Co. 290 was stored in the shade and in the open and 1 lot in each case sprinkled and 1 left unsprinkled. In the second experiment sprinkled and unsprinkled cane of the varieties Co. 290 and P.O.J. 36–M were stored in the shade. One experiment was conducted during 1933 in which lots of sprinkled and unsprinkled P.O.J. 36–M were stored in the open and in the shade and lots of sprinkled and unsprinkled C.P. 28/19 were stored in the shade.

The Brix, apparent sucrose, and apparent purity obtained in these experiments after different intervals of storage are recorded in tables 2, 3, and 4, and the more detailed analyses in table 5.

TABLE 2.—*Brix, apparent sucrose, and apparent purity in sprinkled and unsprinkled cane stored in the shade for different periods during 1930*

Variety and experiment no.	Date of analysis	Duration of storage	Sprinkled cane				Unsprinkled cane			
			Brix	Sucrose	Purity	Extraction	Brix	Sucrose	Purity	Extraction
Second-year stubble:										
Co. 281:		*Days*	°	*Percent*	*Percent*	*Percent*	°	*Percent*	*Percent*	*Percent*
1	Oct. 23	0	14.88	11.57	77.8	.....	14.88	11.57	77.8	.....
	Oct. 27	4	14.68	11.38	77.5	.....	14.94	11.40	76.3	.....
	Oct. 30	7	14.97	11.68	78.0	61	14.79	10.91	73.8	62
	Nov. 6	14	14.89	11.52	77.4	63	15.77	11.56	73.3	59
	Nov. 13	21	14.83	11.47	77.3	63	15.85	11.60	73.2	61
2	Nov. 19	0	16.94	14.21	83.9	64	16.94	14.21	83.9	64
	Nov. 26	7	16.68	14.09	84.5	63	17.35	14.53	83.7	62
	Dec. 3	14	16.69	14.07	84.3	62	17.65	14.20	80.5	62
	Dec. 10	21	16.59	14.03	84.6	62	18.15	14.73	81.2	58
First-year stubble:										
P.O.J. 213:										
1	Oct. 24	0	14.76	11.83	80.1	.....	14.76	11.83	80.1	.....
	Oct. 27	3	14.07	10.99	78.1	.....	14.88	11.85	79.6	.....
	Oct. 31	7	14.72	11.72	79.6	62	15.63	12.05	77.1	58
	Nov. 7	14	14.37	11.17	77.7	62	15.96	11.28	70.7	60
	Nov. 14	21	14.04	10.93	77.8	60	16.12	10.97	68.1	58
2	Nov. 19	0	16.11	13.27	82.4	65	16.11	13.27	82.4	65
	Nov. 26	7	15.69	13.01	82.9	63	16.76	13.97	83.4	60
	Dec. 3	14	15.70	13.08	83.3	62	17.34	13.38	77.2	60
	Dec. 10	21	.....	.....	.....	.....	17.46	12.90	73.9	58
P.O.J. 36–M:										
1	Oct. 24	0	14.26	10.44	73.2	.....	14.26	10.44	73.2	.....
	Oct. 27	3	14.08	10.40	73.9	.....	14.12	9.92	70.3	.....
	Oct. 31	7	14.10	10.53	74.7	61	14.91	9.68	64.9	62
	Nov. 7	14	14.00	10.30	73.6	64	15.46	7.36	47.6	61
	Nov. 14	21	13.82	10.03	72.6	62	15.63	7.12	45.6	58
2	Nov. 19	0	14.98	10.91	72.8	64	14.98	10.91	72.8	64
	Nov. 26	7	14.60	10.87	74.5	65	15.29	11.03	72.1	64
	Dec. 3	14	14.41	10.60	73.6	61	15.77	8.91	56.5	61
	Dec. 10	21	14.47	10.72	74.1	64	16.30	8.79	53.9	59

TABLE 3.—*Brix, apparent sucrose, and apparent purity in sprinkled and unsprinkled sugarcane (first-year stubble) stored in the shade and in the open for different periods during 1931*

Variety and experiment no.	Date of analysis	Duration of storage	Shade							
			Sprinkled cane				Unsprinkled cane			
			Brix	Sucrose	Purity	Extraction	Brix	Sucrose	Purity	Extraction
Co. 281:		*Days*	°	*Percent*	*Percent*	*Percent*	°	*Percent*	*Percent*	*Percent*
1	Oct. 27	0	14.38	10.79	75.0	58	14.38	10.79	75.0	58
	Nov. 3	7	13.85	10.26	74.1	58	14.70	10.62	72.2	57
	Nov. 10	14	13.96	10.44	74.8	58	15.17	10.81	71.3	56
	Nov. 16	20	13.81	10.09	73.1	57	15.51	10.73	69.2	57
2	Nov. 17	0	16.64	13.49	81.1	59	16.64	13.49	81.1	59
	Nov. 27	10	16.09	13.22	82.2	62	16.88	13.67	81.0	61
	Dec. 4	17	15.99	13.14	82.2	60	16.84	13.57	80.6	59
	Dec. 11	24	15.83	12.98	82.0	60	16.85	13.47	79.9	59
C.P. 807:										
1	Oct. 24	0	13.42	10.21	76.1	57	13.42	10.21	76.1	57
	Oct. 27	3	13.45	10.35	77.0	60	13.69	10.32	75.4	58
	Oct. 30	6	13.68	10.47	76.5	56	13.78	9.88	71.7	57
	Nov. 5	12	13.35	9.98	74.8	55	14.61	9.36	64.1	53
	Nov. 13	20	13.69	10.40	76.0	56	15.26	9.65	63.2	56
P.O.J. 234:										
2	Nov. 16	0	16.70	13.86	83.0	55	16.70	13.86	83.0	55
	Nov. 25	9	16.39	13.67	83.4	62	16.72	13.39	80.1	59
	Dec. 2	16	16.13	13.45	83.4	53	17.04	13.23	77.6	55
	Dec. 9	23	15.68	13.05	83.2	58	17.03	12.71	74.6	59
P.O.J. 36–M:										
1	Oct. 26	0	14.37	11.03	76.8	59	14.37	11.03	76.8	59
	Oct. 29	3	14.75	11.27	76.4	59	15.03	11.14	74.1	59
	Nov. 4	9	14.30	10.98	76.8	59	15.18	10.82	71.3	59
	Nov. 10	15	14.06	10.59	75.3	57	15.55	9.39	60.4	57
	Nov. 18	23	13.82	10.28	74.4	59	15.62	9.05	57.9	56
2	Nov. 16	0	15.87	12.58	79.3	58	15.87	12.58	79.3	58
	Nov. 23	7	15.51	12.41	80.0	60	15.89	11.78	74.1	59
	Nov. 30	14	15.08	11.90	78.9	61	16.31	12.01	73.6	60
	Dec. 7	21	15.15	12.16	80.3	60	16.45	11.63	70.7	62

Variety and experiment no.	Date of analysis	Duration of storage	Open							
			Sprinkled cane				Unsprinkled cane			
			Brix	Sucrose	Purity	Extraction	Brix	Sucrose	Purity	Extraction
Co. 281:		*Days*	°	*Percent*	*Percent*	*Percent*	°	*Percent*	*Percent*	*Percent*
1	Oct. 27	0	14.38	10.79	75.0	58	14.38	10.79	75.0	58
	Nov. 3	7	14.04	10.48	74.6	60	14.56	10.43	71.6	59
	Nov. 10	14	14.14	10.47	74.0	56	15.18	10.49	69.1	57
	Nov. 16	20	13.90	10.24	73.7	58	15.49	10.44	67.4	57
2	Nov. 17	0	16.64	13.49	81.1	59	16.64	13.49	81.1	59
	Nov. 27	10	15.97	12.98	81.3	61	16.45	13.40	81.5	60
	Dec. 4	17	16.05	13.19	82.2	58	16.49	13.22	80.2	58
	Dec. 11	24	15.89	13.05	82.1	60	16.51	13.22	80.1	60
C.P. 807:										
1	Oct. 24	0	13.42	10.21	76.1	57	13.42	10.21	76.1	57
	Oct. 27	3	13.70	10.61	77.4	61	13.86	10.51	75.8	60
	Oct. 30	6	13.53	9.98	73.8	56	14.00	10.05	71.8	57
	Nov. 5	12	13.63	9.82	72.0	54	14.85	9.51	64.0	53
	Nov. 13	20	13.79	10.01	72.6	56	15.59	9.90	63.5	55
P.O.J. 234:										
2	Nov. 16	0	16.70	13.86	83.0	55	16.70	13.86	83.0	55
	Nov. 25	9	16.21	13.52	83.4	57	16.64	13.51	81.2	61
	Dec. 2	16	16.07	13.36	83.1	52	16.64	13.27	79.7	54
	Dec. 9	23	16.02	13.45	84.0	55	16.68	12.82	76.9	56
P.O.J. 36–M:										
1	Oct. 26	0	14.37	11.03	76.8	59	14.37	11.03	76.8	59
	Oct. 29	3	14.51	11.01	75.9	59	15.25	11.49	75.3	60
	Nov. 4	9	14.32	10.88	76.0	58	15.35	10.67	69.5	58
	Nov. 10	15	14.24	10.47	73.5	57	15.83	9.49	59.9	56
	Nov. 18	23	13.99	10.29	73.6	60	16.22	8.78	54.1	57
2	Nov. 16	0	15.87	12.58	79.3	58	15.87	12.58	79.3	58
	Nov. 23	7	15.48	12.29	79.4	60	15.65	12.57	80.3	60
	Nov. 30	14	15.24	11.88	78.0	63	15.57	11.73	75.3	60
	Dec. 7	21	15.20	12.22	80.4	61	15.96	12.12	75.9	61

TABLE 4.—*Brix, apparent sucrose, and apparent purity in sprinkled and unsprinkled sugarcane stored in the shade and in the open for different periods during 1932 and 1933*

Variety and experiment no.	Cane stored in—	Date of analysis	Duration of storage	Sprinkled cane				Unsprinkled cane			
				Brix	Sucrose	Purity	Extraction	Brix	Sucrose	Purity	Extraction
Plant cane:											
Co. 290:		1932	*Days*	°	*Pct.*	*Pct.*	*Pct.*	°	*Pct.*	*Pct.*	*Pct.*
1	Shade	Nov. 4	0	15.46	11.94	77.2	65	15.46	11.94	77.2	65
		Nov. 11	7	15.47	11.93	77.1	65	15.94	12.00	75.3	64
		Nov. 18	14	15.40	11.80	76.6	66	16.37	11.85	72.4	65
	Open	Nov. 4	0	15.46	11.94	77.2	65	15.46	11.94	77.2	65
		Nov. 11	7	15.34	11.85	77.2	59	16.07	11.98	74.5	62
		Nov. 18	14	15.41	11.47	74.4	66	16.56	11.42	69.0	65
2	Shade	Nov. 18	0	15.83	12.46	78.7	65	15.83	12.46	78.7	65
		Nov. 25	7	15.58	12.16	78.0	66	16.17	12.52	77.4	68
		Dec. 3	15	15.62	12.32	78.9	67	16.60	12.41	74.8	64
		Dec. 9	21	15.71	12.42	79.1	64	16.74	11.99	71.6	66
		Dec. 16	28	15.47	12.48	80.7	68	16.90	12.47	73.8	69
P.O.J. 36–M:											
2	Shade	Nov. 18	0	15.14	12.08	79.8	61	15.14	12.08	79.8	61
		Nov. 25	7	14.67	11.57	78.9	62	16.00	12.72	79.5	63
		Dec. 3	15	14.81	11.59	78.3	61	16.43	12.74	77.5	60
		Dec. 9	21	14.64	11.43	78.1	59	16.75	12.27	73.3	60
		Dec. 16	28	14.47	11.46	79.2	63	16.80	12.13	72.2	61
First-year stubble:											
P.O.J. 36–M:		1933									
1	Shade	Oct. 18	0	14.23	10.92	76.7	55	14.23	10.92	76.7	55
		Oct. 25	7	13.96	10.81	77.4	58	15.04	10.03	66.7	58
		Nov. 1	14	13.52	10.32	76.3	62	15.25	9.15	60.0	60
		Nov. 10	23	13.42	10.39	77.4	60	15.74	8.90	56.5	57
	Open	Oct. 18	0	14.23	10.92	76.7	55	14.23	10.92	76.7	55
		Oct. 25	7	13.66	10.38	76.0	59	15.10	9.18	60.7	58
		Nov. 1	14	13.66	10.26	75.1	60	15.17	8.22	54.2	59
		Nov. 10	23	13.38	9.78	73.1	56	15.53	7.83	50.4	55
C.P. 28/19:											
1	Shade	Oct. 20	0	16.16	12.14	75.1	52	16.16	12.14	75.1	52
		Oct. 27	7	15.71	11.96	76.1	53	16.83	12.19	72.4	55
		Nov. 3	14	16.11	12.61	78.3	60	16.90	11.89	70.4	59
		Nov. 10	21	16.24	12.68	78.1	54	17.69	11.79	66.7	51

The results are conclusive in showing comparatively little loss of sucrose or drop in purity in sprinkled cane when stored in either the shade or in the open for 20 to 24 days. There was a tendency in most instances for the Brix, total solids, and sucrose to decrease with the continuation of storage. There may have been some dilution as a result of sprinkling, because in other experiments cane when kept wet sometimes increased in weight. Some loss in invert sugar and hence in total solids is to be expected as a result of respiration, especially if there is rooting and sprouting, which happened in certain instances. Whether or not this loss was partly or wholly at the expense of sucrose or of the starch in the starch zones [8] above the root bands is not known, as rooting and sprouting did not seem to affect the purity.

In the one experiment in which C.P. 28/19 (tables 4, 5) was used, there was a tendency for the purity to increase and the invert sugar to decrease in the sprinkled cane. Additional results will be required to determine whether or not this tendency is significant or characteristic of this variety when sprinkled.

[8] The starch deposits are in the growth regions or intercalary meristems above the root bands.

TABLE 5.—*Detailed analysis of sprinkled and unsprinkled sugarcane stored for different periods of time, in the shade and in the open, during 1931, and in the shade during 1932 and 1933*

Variety and experiment no.	Date of analysis	Duration of storage	Shade													
			Sprinkled cane							Unsprinkled cane						
			Acidity [1]	pH	Dry substance	True purity	Invert sugars [2]	Ash [2]	Organic nonsugars [2]	Acidity [1]	pH	Dry substance	True purity	Invert sugars [2]	Ash [2]	Organic nonsugars [2]
Co. 281 (first-year stubble):	1931	*Days*			*Percent*	*Percent*	*Percent*	*Percent*	*Percent*			*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	Oct. 27	0	2.85	------	13.68	80.77	10.57	4.41	4.25	2.85	------	13.68	80.77	10.57	4.41	4.25
	Nov. 3	7	2.70	------	13.22	80.79	10.14	4.46	4.61	2.70	------	13.97	77.74	11.78	4.22	6.26
	Nov. 10	14	2.80	------	13.35	79.78	10.36	4.34	5.52	3.00	------	14.50	77.38	13.23	4.20	5.19
	Nov. 16	20	3.10	5.24	13.10	79.54	10.64	4.43	5.39	3.20	5.28	14.72	76.47	13.82	4.44	5.27
2	Nov. 17	0	3.00	5.27	15.93	86.82	4.87	3.57	4.74	3.00	5.27	15.93	86.82	4.87	3.57	4.74
	Nov. 27	10	3.00	5.31	15.43	87.23	4.69	3.55	4.53	3.00	5.31	16.18	86.89	5.31	3.45	4.35
	Dec. 11	24	2.50	5.27	15.22	86.60	4.66	3.55	5.19	2.80	5.27	16.26	84.75	6.08	3.64	5.53
C.P. 807 (first-year stubble):																
	Oct. 24	0	------	------	12.60	83.81	10.29	------	------	------	------	12.60	83.81	10.29	------	------
	Oct. 27	3	2.40	------	13.02	81.57	10.15	------	------	2.30	------	13.13	79.89	11.67	3.69	4.75
	Oct. 30	6	2.30	------	12.80	81.25	10.45	3.62	4.68	2.30	------	13.55	75.57	14.26	3.51	6.66
	Nov. 5	12	2.55	------	12.85	80.16	11.78	3.67	4.39	2.75	------	13.96	71.78	19.26	3.42	5.54
	Nov. 13	20	2.45	------	13.05	81.14	10.69	3.60	5.17	2.80	------	14.55	71.00	21.18	3.58	4.24
P.O.J. 234 (first-year stubble):																
2	Nov. 16	0	------	5.35	16.18	87.21	4.80	2.90	5.09	------	5.35	16.18	87.21	4.80	2.90	5.09
	Nov. 25	9	2.40	5.30	15.82	88.50	4.20	2.69	4.61	2.40	5.30	16.43	83.75	8.27	2.89	5.09
	Dec. 2	16	2.20	5.35	15.66	88.05	4.10	2.90	4.95	2.40	5.30	16.62	82.37	9.98	2.66	4.99
	Dec. 9	23	2.20	5.28	15.23	87.46	4.37	2.82	5.35	2.50	5.15	16.64	81.79	9.86	2.74	5.61
P.O.J. 36–M (first-year stubble):																
1	Oct. 26	0	------	------	13.73	82.45	11.68	3.06	2.81	------	------	13.73	82.45	11.68	3.06	2.81
	Oct. 29	3	1.85	------	13.90	81.37	10.73	2.70	5.20	1.85	------	14.35	79.58	13.23	2.66	4.53
	Nov. 4	9	2.00	------	13.83	80.98	11.78	2.78	4.46	2.00	------	14.68	76.23	17.09	2.85	3.83
	Nov. 10	15	2.00	------	13.59	80.43	12.52	2.88	4.17	2.25	------	15.07	68.75	24.47	2.65	4.13
	Nov. 18	23	2.10	5.34	13.31	79.79	12.11	2.81	5.29	2.30	5.39	14.85	66.33	26.24	3.07	4.36
2	Nov. 16	0	------	5.39	15.33	84.34	9.13	2.50	4.03	------	5.39	15.33	84.34	9.13	2.50	4.03
	Nov. 23	7	1.90	5.40	15.05	85.32	8.15	2.59	3.93	2.00	5.39	15.44	80.18	12.88	2.66	4.28
	Nov. 30	14	1.85	5.42	14.49	85.02	8.72	2.87	3.39	2.30	5.43	15.85	77.35	13.64	2.66	6.35
	Dec. 7	21	1.80	5.32	14.71	85.52	8.19	2.56	3.73	2.00	5.25	16.06	77.83	15.21	2.51	4.45
Co. 290 (plant cane):	1932															
1	Nov. 4	0	2.90	5.23	14.77	83.07	8.87	4.14	3.92	2.90	5.23	14.77	83.07	8.87	4.14	3.92
	Nov. 11	7	2.85	5.20	14.88	83.80	8.44	3.51	4.25	2.95	5.20	15.31	82.30	10.67	3.55	3.48
	Nov. 18	14	2.85	5.26	14.83	82.60	9.08	3.48	4.84	3.05	5.24	15.78	79.18	12.26	3.56	5.00
2	do	0	2.85	5.28	15.19	84.53	7.37	3.67	4.43	3.85	5.28	15.19	84.53	7.37	3.67	4.43
	Dec. 3	15	------	5.35	15.05	83.32	8.23	3.68	4.77	2.90	5.33	16.01	80.51	10.90	3.64	4.95

P.O.J. 36–M (first-year stubble):																
2	Nov. 18	0	2.05	5.35	14.72	84.85	7.83	2.67	4.65	2.05	5.35	14.72	84.85	7.83	2.67	4.65
	Dec. 3	15	2.15	5.44	14.27	83.67	8.76	2.97	4.60	2.15	5.40	16.08	81.72	11.05	2.68	4.55
C.P. 28/19 (first-year stubble):	1933															
1	Oct. 20	0	2.20	5.18	15.63	81.13	8.86	4.13	5.88	2.20	5.18	15.63	81.13	8.86	4.13	5.88
	Oct. 27	7	1.99	5.24	14.99	81.45	8.64	4.38	5.53	2.13	5.26	16.18	77.94	11.85	4.18	6.03
	Nov. 3	14	1.89	5.25	15.49	82.44	7.33	4.15	6.08	2.16	5.25	16.45	74.77	14.67	4.44	6.12
	Nov. 10	21	1.85	5.34	15.57	83.88	7.13	4.05	4.90	2.04	5.31	16.97	74.60	16.67	4.15	4.58

Variety and experiment no.	Date of analysis	Duration of storage	Open													
			Sprinkled cane							Unsprinkled cane						
			Acidity [1]	pH	Dry substance	True purity	Invert sugars [2]	Ash [2]	Organic non-sugars [2]	Acidity [1]	pH	Dry substance	True purity	Invert sugars [2]	Ash [2]	Organic non-sugars [2]
Co. 281 (first-year stubble):	1931	*Days*			*Percent*	*Percent*	*Percent*	*Percent*	*Percent*			*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	Oct. 27	0	2.85	-------	13.68	80.77	10.57	4.41	4.25	2.85	-------	13.68	80.77	10.57	4.41	4.25
	Nov. 3	7	2.70	-------	13.36	80.98	10.01	4.30	4.71	2.70	-------	13.92	78.74	12.01	4.25	5.00
	Nov. 10	14	2.80	-------	13.41	80.01	10.63	4.28	5.08	3.20	-------	14.42	75.86	14.63	4.05	5.46
	Nov. 16	20	3.00	5.33	13.16	79.33	10.46	4.79	5.42	3.40	5.28	14.67	75.12	14.89	4.43	5.56
2	Nov. 17	0	3.00	5.27	15.93	86.82	4.87	3.57	4.74	3.00	5.27	15.93	86.82	4.87	3.52	4.74
	Nov. 27	10	3.00	5.31	15.38	86.80	4.79	3.56	4.85	3.00	5.31	15.91	86.11	5.32	3.58	4.99
	Dec. 11	24	2.50	5.29	15.48	86.50	4.72	3.55	5.23	2.70	5.26	15.87	84.88	5.96	3.73	5.43
C.P. 807 (first-year stubble):																
1	Oct. 24	0	-------	-------	12.60	83.81	10.29	-------	-------	-------	-------	12.60	83.81	10.29	-------	-------
	Oct. 27	3	2.30	-------	13.11	82.53	9.90	3.55	4.02	2.45	-------	13.50	78.59	12.08	3.27	6.06
	Oct. 30	6	2.30	-------	13.00	80.08	10.88	3.69	5.35	2.30	-------	13.97	77.52	14.22	3.44	4.92
	Nov. 5	12	2.55	-------	13.28	77.03	12.85	3.63	6.49	2.75	-------	14.37	71.19	21.11	3.31	4.39
	Nov. 13	20	2.55	-------	13.16	78.27	13.06	3.72	4.95	2.80	-------	14.95	69.90	21.99	3.37	4.74
P.O.J. 234 (first-year stubble):																
2	Nov. 16	0	-------	5.35	16.18	87.21	4.80	2.90	5.09	-------	5.35	16.18	87.21	4.80	2.90	5.09
	Nov. 25	9	2.35	5.30	15.80	87.78	4.51	2.77	4.94	2.40	5.30	16.16	86.76	5.63	2.81	4.80
	Dec. 2	16	2.20	5.35	15.63	87.78	4.40	2.94	4.88	2.40	5.30	16.16	84.53	8.20	2.64	4.63
	Dec. 9	23	2.20	5.28	15.64	87.85	4.03	2.92	5.20	2.40	5.17	16.32	82.72	8.55	2.80	5.93
P.O.J. 36–M (first-year stubble):																
1	Oct. 26	0	-------	-------	13.73	82.45	11.68	3.06	2.81	-------	-------	13.73	82.45	11.68	3.06	2.81
	Oct. 29	3	2.00	-------	14.05	80.64	11.42	2.85	5.09	1.90	-------	14.70	80.20	12.87	2.61	4.32
	Nov. 4	9	2.00	-------	13.91	79.22	13.42	2.70	4.66	2.00	-------	14.62	75.38	17.59	2.87	4.16
	Nov. 10	15	2.00	-------	13.68	79.09	13.56	2.87	4.48	2.15	-------	15.35	68.66	24.23	2.67	4.43
	Nov. 18	23	2.15	5.35	13.41	79.12	13.19	2.75	4.94	2.60	5.34	15.61	62.72	29.02	3.05	5.21
2	Nov. 16	0	-------	5.39	15.33	84.34	9.13	2.50	4.03	-------	5.39	15.33	84.34	9.13	2.50	4.03
	Nov. 23	7	1.90	5.40	15.03	84.96	8.32	2.66	4.06	2.00	5.39	15.13	83.81	9.19	2.57	4.43
	Nov. 30	14	1.85	5.44	14.67	83.16	8.83	2.79	5.22	2.25	5.40	15.07	81.75	11.96	2.87	3.42
	Dec. 7	21	1.75	5.32	15.01	84.41	8.09	2.52	4.98	2.00	5.23	15.50	81.29	12.26	2.51	3.94

[1] Determined by titrating 10 cc of juice with 0.1 N sodium hydroxide solution.

[2] Percentage based on dry substance.

The results obtained in connection with unsprinkled cane are in a number of ways in striking contrast to those obtained from sprinkled cane. Except in experiment 2, 1931 (tables 3 and 5), in cane stored in the open when there was considerable rain, the Brix and dry substance increased with the continuation of storage, showing the effect of drying. In the apparent-sucrose readings the effect of drying was obscured in most cases by rapid deterioration, especially when deterioration was marked. In some instances there was a large drop in sucrose. There was a drop in apparent and true purity in all the unsprinkled cane and in some cases it was very large. In most instances the drop in apparent purity was slightly greater than in true purity, indicating the influence of invert sugar on the apparent purity determination. The increase in invert sugar with the continuation of storage was definitely related to the loss of sucrose and drop in purity, indicating that deterioration is primarily a matter of inversion, especially as there was no significant change in acidity or pH and the organic nonsugars remained practically constant in both sprinkled and unsprinkled cane. The slight change in acidity that did occur in some cases, disregarding that accounted for by the effect of drying, does not signify that micro-organisms played any part in deterioration.

The data indicate that maturity as measured by apparent or true purity affects the rate of deterioration, for as the cane matures it seems to deteriorate less rapidly. The behavior of P.O.J. 36–M during 1930 (table 2) is an exception. It is possible that the cloudy and rainy weather of the first few days in experiment 2 dealing with P.O.J. 36–M, and absent in experiment 1 (fig. 1, 1930 data), may have had a relation to the difference in the amount of deterioration. However, it may also be possible that other unknown factors play a part in the varying behavior of different lots of cane of a given variety.

That there is a varietal factor affecting deterioration is very evident from the data presented. Although all varieties show little inversion when kept wet by sprinkling there is a pronounced difference in the behavior of the different varieties when stored under conditions that favor the drying out of the cane, as found in this and other studies. Co. 281 is very resistant, while P.O.J. 36–M and C.P. 807 appear to be the most susceptible to deterioration. The results with the other varieties are too meager to establish the relationship toward one another, but it can be concluded that their susceptibility is intermediate between Co. 281 and P.O.J. 36–M.

TEMPERATURE AND MOISTURE RELATIONS IN SMALL PILES

The effect of temperature and moisture on deterioration must be considered along with the effect of maturity. It will be noted that cane of a given variety in the second and later experiment in each of the first three seasons showed less deterioration than in the first,[9] and normally it would be expected that the cane in the second experiments would be subject to a lower temperature than in the first, but that is not always true. Figure 1 gives some of the weather records, including the mean of the daily maximum and minimum temperatures, rainfall, etc., for the periods during which the various experiments were run.

[9] Although two experiments involving P.O.J. 36–M were conducted during the early and latter part of the season of 1933, the conditions under which they were conducted were not entirely comparable. The results of the second experiment will be discussed later.

It will be noted that the temperatures during the first 15 to 18 days were fairly comparable during the two experiments in both 1930 and

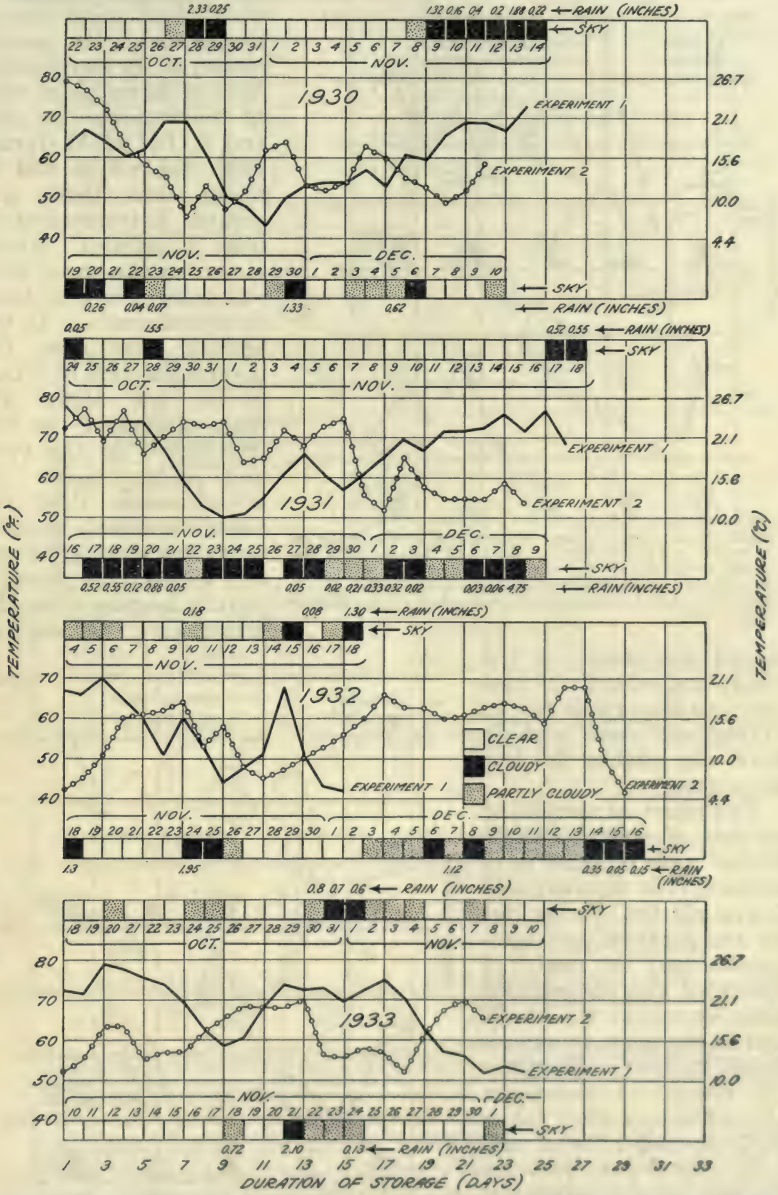

FIGURE 1.—Daily averages of maximum and minimum air temperatures, condition of sky as to cloudiness, etc., and rainfall during experiments with small piles in 1930, 1931, 1932, and 1933. The data regarding the condition of the sky are limited to the daytime.

1931. In 1930 there was considerable cloudiness and rainfall during the latter part of the first experiment. Cloudiness continued on into

the second experiment and there was rain during 3 of the first 5 days. In 1931 the weather was predominantly clear during the first experiment and predominantly cloudy and rainy during the second. On examination of the comparable data on unsprinkled cane of the varieties Co. 281 and P.O.J. 36–M during 1931 (table 3) it will be found that there was greater deterioration in both varieties when stored in the open than when stored in the shade in experiment 1. In the second experiment the reverse was true of P.O.J. 36–M, and there was little difference in Co. 281 stored in the open and in the shade. It would seem that the cloudy and wet weather prevalent during the second experiment played a part in keeping down deterioration. Although no record was made of the wind, undoubtedly it also plays an important role in drying out cane and in that way affects the loss of sucrose.

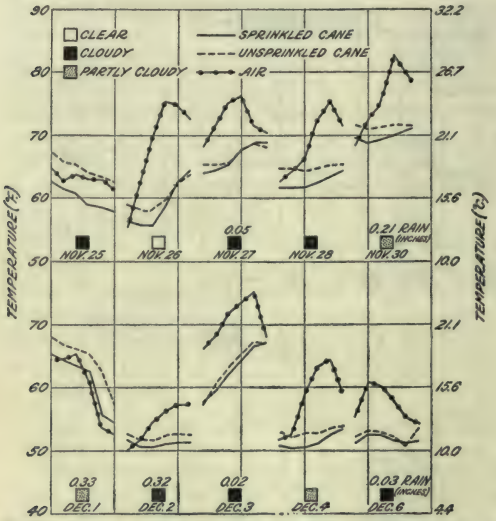

FIGURE 2.—Air temperature, temperatures at the center of sprinkled and unsprinkled small piles of cane stored in the shade, condition of sky as to cloudiness, etc., and rainfall. The temperature curves were plotted from readings taken at 7, 9, and 11 a.m. and 1, 3, and 5 p.m. on the days given. Experiment 2, 1931.

The effect of sprinkling on the temperatures within the piles of cane is of interest. In figures 2 and 3 are plotted curves for air temperature and temperatures at the center of sprinkled and unsprinkled piles stored in the shade and in the open, in experiment 2, 1931. Readings by means of resistance thermometers were taken at 7, 9, and 11 a.m. and 1, 3, and 5 p.m. just before sprinkling on different days, some of which were in succession. In figure 4 are plotted similar curves

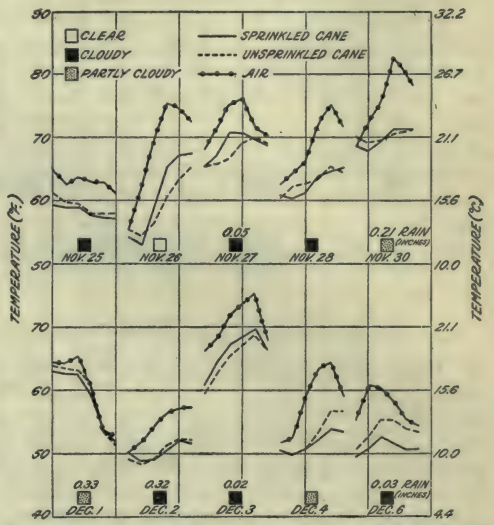

FIGURE 3.—Air temperature, temperatures at the center of sprinkled and unsprinkled small piles of cane stored in the open, condition of sky as to cloudiness, etc., and rainfall. The temperature curves were plotted from readings taken at 7, 9, and 11 a.m. and 1, 3, and 5 p.m. on the days given. Experiment 2, 1931.

in connection with cane stored in the shade during experiment 2, 1932.[10]

The temperature within the sprinkled piles was generally lower than in the unsprinkled piles, and the difference was generally greater in

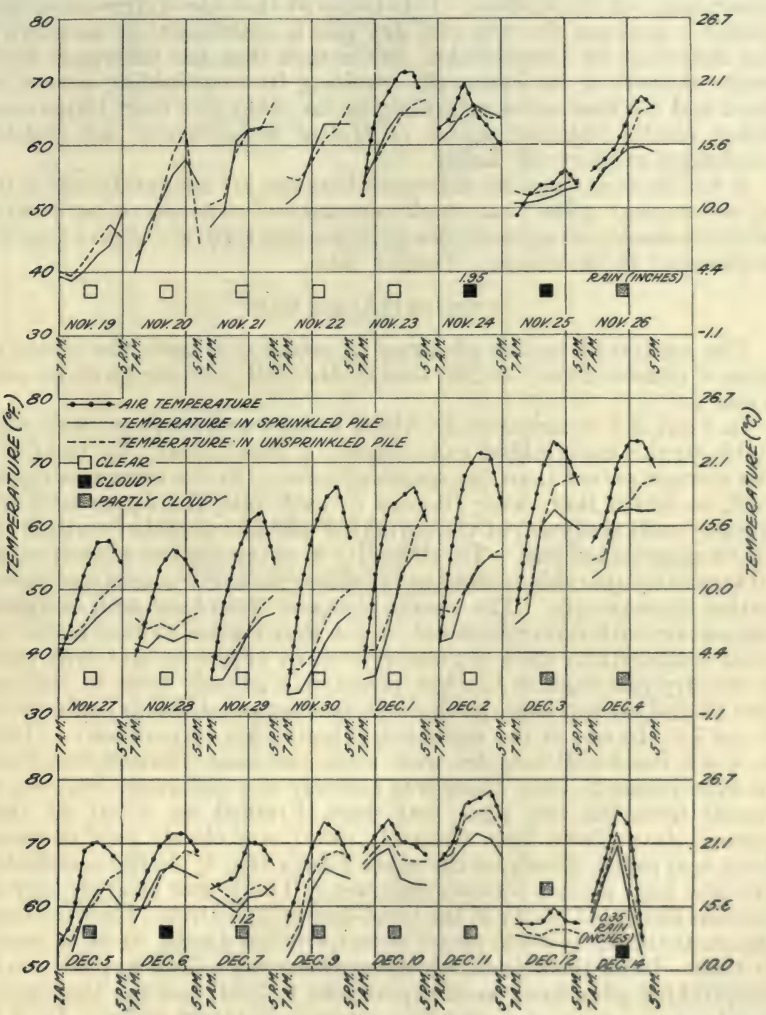

FIGURE 4.—Air temperature, temperatures at the center of sprinkled and unsprinkled small piles of cane stored in the shade, condition of sky as to cloudiness, etc., and rainfall. The temperature curves were plotted from daily readings (except Dec. 8 and 13) taken at 7, 9, and 11 a.m. and 1, 3, and 5 p.m. throughout the experiment. Experiment 2, 1932.

the shade than in the open. A lowering of the temperature in the sprinkled piles as a result of increased evaporation was expected. The actual differences in temperature between sprinkled and unsprinkled

[10] Temperature readings also were taken during 1933 in connection with sprinkled and unsprinkled cane stored in the shade and in the open. They were so similar to the foregoing records that they will not be presented.

cane or between cane stored in the shade and in the open, however, were not large. The temperature of the cane stored in the open tended to change more rapidly in response to a change in air temperature than did the cane stored in the shade and consequently showed a wider range of fluctuation. It is believed that the difference in temperature between the wet and dry pile is insufficient to account for the difference in deterioration, but rather that the difference in the water content of the cane cells resulting from sprinkling on the one hand and the absence of sprinkling on the other is of more importance. Other results obtained under controlled temperature and moisture conditions support this belief.

It will be seen from the difference between air temperature and that of the storage piles that small amounts of cane serve as a rather effective insulation against change in temperature, which is of practical importance in the storage of sugar cane.

STORAGE IN LARGE PILES

The analytical results obtained in connection with the storage of piles of cane of from 7 to 260 tons on the mill yard are given in tables 6 and 7.

In 2 out of 3 experiments in which factory-mill analyses were made (table 6) the unsprinkled cane showed a lower purity by the end of the storage period than the sprinkled cane. In the third experiment, 1932, in which there were 70 tons in each pile, the apparent purity (factory-mill analyses) of the sprinkled pile was slightly less than that of the unsprinkled pile. The difficulty in obtaining two piles of cane of 70 tons of comparable sucrose composition should be considered in evaluating these results. The results obtained from hand-mill samples in connection with this experiment, which were certain to be of rather uniform composition, show a greater drop in apparent and true purity in the dry pile than in the wet pile and a greater drop in the samples placed on top than in those at the center of the dry pile (tables 6 and 7). In one of the other two experiments (experiment 1, 1931), in which hand-mill samples were used, the same relation was found. In experiment 2, 1931, there was scarcely any difference between the results from the two piles, but since it rained on 5 out of the 6 storage days (from Dec. 15 to 21, 1931), was cloudy on 4 of these 6 days, and partly cloudy on the other 2 days (fig. 5, *A*) the unsprinkled pile was kept almost continuously wet. There was scarcely any significant change of purity in the hand-mill samples from either the top or the center of the 260-ton pile of cane sprinkled during 10 days' storage in 1933. In all these tests, whenever there was a drop in purity in the unsprinkled piles (such as in experiment 1, 1931, and the 1932 experiment) there was a corresponding increase in invert sugar. As in the tests conducted on small piles, this fact also indicates that the loss of sucrose was primarily due to inversion. The fact that there was no significant change in acidity or pH, nor any other sign of an abnormal condition in any of the piles, strongly indicates the feasibility of storing and sprinkling cane in large piles.

TABLE 6.—*Brix, apparent sucrose, apparent purity, and extraction in sprinkled and unsprinkled piles of sugarcane of 7 to 260 tons*

Variety and experiment no.	Sample	Position of sample	Size of pile	Date of analysis	Duration of storage	Sprinkled cane				Unsprinkled cane			
						Brix	Sucrose	Purity	Extraction	Brix	Sucrose	Purity	Extraction
			Tons	1930	*Days*	°	*Percent*	*Percent*	*Percent*	°	*Percent*	*Percent*	*Percent*
P.O.J. 213 (first-year stubble)	Factory mill (normal juice)	Entire pile	7	Nov. 6	3	13.58	10.45	77.0		16.05	11.98	74.6	
				1931									
P.O.J. 213:													
1 (second-year stubble)	Hand mill	Check	25	Nov. 11[1]	0	16.14	13.38	82.9	55	16.14	13.38	82.9	55
	do	Top of pile	25	Nov. 16	4	15.64	12.65	80.9	55	16.66	12.55	75.3	56
	do	do	25	Nov. 18	6	15.47	12.52	80.9	60	16.69	11.98	71.8	57
	do	Center of pile	25	do	6	15.37	12.29	80.0	61	16.12	12.56	77.9	59
	Factory mill (normal juice)	Entire pile	25	do	6	12.58	9.06	72.0		13.75	9.59	69.8	
2 (third-year stubble)	Hand mill	Check	30	Dec. 15	0	16.21	14.11	87.1		16.21	14.11	87.1	
		Top of pile	30	Dec. 22	7	15.78	13.60	86.2		16.31	14.06	86.2	
		Center of pile	30	do	7	15.69	13.43	85.6		16.11	13.85	86.0	
				1932									
P.O.J. 213 (third-year stubble)	Hand mill	Check	70	Oct. 31	0	15.42	12.67	82.2	62	15.42	12.67	82.2	62
		Top of pile	70	Nov. 3	4	15.47	12.74	82.4	64	15.66	12.83	81.9	65
		do	70	Nov. 7	7	15.74	12.69	80.6	61	16.27	12.50	76.8	63
		Center of pile	70	do	7	15.58	12.69	81.5	63	15.80	12.55	79.4	64
	Factory mill (normal juice)	Entire pile	70	do	7	14.70	11.07	75.3		16.48	12.63	76.6	
				1933									
P.O.J. 36–M (first-year stubble)[2]	Hand mill	Check	260	Nov. 27	0	14.81	11.44	77.3	59				
		Top of pile	260	Dec. 7	10	14.38	11.15	77.5	60				
		Center of pile	260	do	10	14.39	11.13	77.4	60				

[1] The check sample was ground and analyzed Nov. 11, whereas the piles were not finished until Nov. 12.

[2] The pile consisted of a mixture of varieties.

TABLE 7.—*Detailed analysis of hand-mill samples stored on top and at the center of sprinkled and unsprinkled piles of sugarcane, ranging from 25 to 260 tons* [1]

Variety and experiment no.	Position of sample	Date of analysis	Duration of storage	Sprinkled cane							Unsprinkled cane						
				Acidity (0.1 N NaOH per 10 cc of juice)	pH	Dry substance	True purity	Invert sugars	Ash	Organic non-sugars	Acidity (0.1 N NaOH per 10 cc of juice)	pH	Dry substance	True purity	Invert sugars	Ash	Organic non-sugars
P.O.J. 213:		1931	*Days*			*Percent*	*Percent*	*Percent*	*Percent*	*Percent*			*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1 (second-year stubble).	Check	Nov. 11	0	1.55		15.78	87.57	6.95	1.82	3.66	1.55		15.78	87.57	6.95	1.82	3.66
	Top of pile	Nov. 18	7	1.85	5.39	15.12	85.58	8.51	1.48	4.07	1.95	5.39	16.39	78.04	16.08	1.90	3.98
	Center of pile	do	7	1.90	5.36	15.12	85.38	8.24	1.98	4.40	1.85	5.39	15.81	84.00	10.00	2.04	3.96
2 (third-year stubble).	Check	Dec. 15	0	2.00	5.26	15.84	89.84	2.61	2.49	5.06	2.00	5.26	15.84	89.84	2.61	2.49	5.06
	Top of pile	Dec. 22	7	1.90	5.36	15.26	90.89	2.72	2.62	3.77	1.90	5.36	15.88	90.49	2.48	2.58	4.41
	Center of pile	do	7	1.90	5.36	15.19	90.68	2.79	2.70	3.83	1.90	5.36	15.72	90.39	2.50	2.68	4.43
		1932															
P.O.J. 213 (third-year stubble).	Check	Oct. 31	0	1.20	5.42	15.19	86.37	7.56	2.06	4.01	1.20	5.42	15.19	86.37	7.56	2.06	4.01
	Top of pile	Nov. 7	7	1.15	5.40	15.18	86.89	7.38	2.14	3.59	1.20	5.42	16.01	81.83	10.41	2.06	5.70
	Center of pile	do	7	1.10	5.42	15.33	86.11	7.35	1.99	4.55	1.10	5.42	15.84	82.70	8.20	1.99	7.11
		1933															
P.O.J. 36–M (first-year stubble).[2]	Check	Nov. 27	0	1.47	5.34	14.15	82.76	9.24	3.49	4.51							
	Top of pile	Dec. 7	10	1.44	5.41	13.92	82.26	9.20	3.63	4.91							
	Center of pile	do	10	1.42	5.42	13.89	82.36	9.08	3.58	4.98							

[1] Piles in experiment 1, 1931, contained 25 tons; in experiment 2, 1931, 30 tons; in the 1932 experiment 70 tons, and in the 1933 experiment 260 tons.
[2] The pile was a mixture of varieties.

TEMPERATURE AND MOISTURE RELATIONS IN LARGE PILES

In figure 5 a comparison is shown of (1) air temperature and temperatures at the center of the sprinkled and unsprinkled piles of cane (30 tons) in experiment 2, 1931, and in the 1932 experiment (70 tons), and (2) air temperature and temperatures at the center of the sprinkled pile (260 tons) in the 1933 experiment. The rainfall and the condition of the sky as to cloudiness are also given.

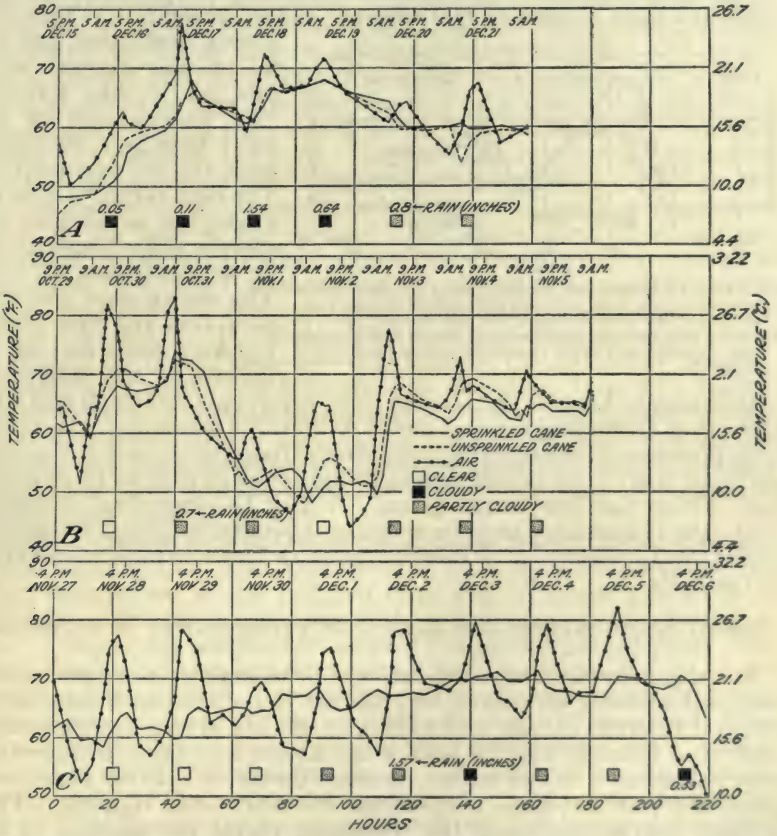

FIGURE 5.—Air temperature, temperatures at the center of sprinkled and unsprinkled piles of 30 tons (1931) and 70 tons (1932), and of a sprinkled pile of 260 tons (1933) of cane stored in the open; condition of sky as to cloudiness, etc., and rainfall. The temperature curves were plotted from readings taken frequently (usually every 2 hours) throughout each experiment: *A*, Experiment 2, 1931; *B*, 1932 experiment; *C*, 1933 experiment.

It will be seen that there was not much difference between the temperature of the sprinkled and unsprinkled piles, although it was generally slightly lower in the sprinkled piles even during the 1931 experiment, when the weather was predominantly cloudy and rainy. The difference in the 1932 experiment is not sufficient, it is believed, to account for the difference in deterioration. It is significant that although the temperatures of the pile lag behind that of the air, they

tend to fluctuate with it. Even in the pile of 260 tons, when by the end of the storage period there was slight nodal root growth (1 to 1.5 inches long), the temperature of the pile laggingly fluctuated with that of the air. It shows that even in piles as large as 260 tons the heat of respiration is dissipated in a sufficiently rapid manner to be no source of hazard, at least as long as the duration of the storage period is not too great. It also signifies an absence of the action of micro-organisms.

The air temperature and the temperatures at the center of two mill-yard piles of cane of 800 tons are shown in figure 6. The piles joined each other and pile no. 2 was started when pile no. 1 was finished. The temperature of pile no. 1 laggingly fluctuated with the air temperature. The fluctuation in pile no. 2 was not so definite, but there was no tendency for an accumulation of heat. The direction of the wind as well as the time of piling may have had an influence on this difference.

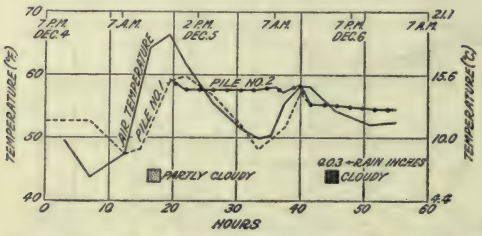

FIGURE 6.—Air temperature, temperatures at the center of two mill-yard piles of cane (unsprinkled) of about 800 tons each, condition of sky as to cloudiness, etc., and rainfall (Dec. 4 to 6, 1931). The temperature curves were plotted from readings taken approximately every 2 hours throughout the period of storage.

It has been shown in the storage tests, involving both small and large piles, that sprinkling reduces deterioration to a minimum, that there is no pronounced change in composition of the juice in cane stored wet, and that there is no accumulation of heat even in piles as large as 800 tons within the time limits given. It may be concluded, therefore, that cane if sprinkled may be safely and profitably stored for limited periods in Louisiana, thus insuring more or less continuous operation of the mills.

MISCELLANEOUS EXPERIMENTS BEARING ON DETERIORATION OF SUGARCANE

If sugar losses in harvested cane are to be kept at a minimum, it is essential to know what may be expected to occur in such cane in the interval between cutting and milling or placing in piles for sprinkling. This time interval may be only a few hours, but more frequently it may extend to a day or more. In some instances it is the practice to place the cane in small piles across the rows after topping. Then without further stripping the remaining leaves are allowed to dry sufficiently for burning.[11] Thus, a few experiments were conducted in which the rate of inversion of sucrose in stripped and unstripped cane, and of checking inversion by sprinkling, once it has started, were studied.

DETERIORATION IN STRIPPED AND UNSTRIPPED CANE

Three experiments were conducted in which the rate of inversion of sucrose in stripped and unstripped cane of two varieties (table 8) was studied. The method of sampling was the same in all three experiments. A plot of uniform cane from a limited area was cut off at the

[11] Although these experiments were not designed to cover this particular case, it is believed that they throw some light on it.

ground and placed in a long pile across the furrows without stripping. In each experiment twenty-five 30-stalk samples were selected by drawing stalks for each sample at random over the entire pile. After selection, 15 of these samples, taken at random from the lot, were stripped in the same manner that is used with mill cane. The leaves and trash were left on the remaining 10 samples. The stalks of each sample were bound together by wire fastened around the sample in 2 or 3 places. In each experiment five of these stripped samples were analyzed immediately as checks. The remaining samples were stored as follows: In the first experiment, 5 stripped and 5 unstripped samples were stored at 65° F. and 96 percent relative humidity and at 65° and 75 percent relative humidity on racks in storage rooms 10 by 12 feet by about 9 feet high. In the two other experiments, 5 stripped and 5 unstripped samples were stored on each of two racks (1.5 feet high and 16 feet long) in the open. The samples on the one rack were sprinkled and those on the other were left unsprinkled. The samples were spread out over the racks and all the wire bands were released except at the base of the sample. The upper parts of all samples were then spread out to afford ample opportunity for evaporation to take place. The tops (upper portion of stripped and unstripped cane) of the samples faced south and were fully exposed to the sun, when shining, throughout the day. The sky was clear throughout the duration of the first of these two experiments, the minimum temperature ranging from 36° to 53°, and the maximum from 65° to 80°. During the second experiment the sky was clear 3 days, partly cloudy 3 days, and cloudy 2 days (including the day of setting up and the day of taking down the experiment). The rainfall was 0.15 inch; the range of minimum temperatures from 40° to 65°; and that of maximum temperatures from 68° to 81°.

Weight [12] losses were not determined in the first of the three experiments. In the two other experiments, the weight losses were accurately determined in the stripped cane and an effort was made to determine indirectly some notion of the weight losses in the unstripped cane. An average weight was taken of the 15 stripped samples. The losses given were obtained by subtracting the average weight of the unstripped samples of a given treatment after stripping from the average original weight of the stripped samples. This method, when the samples are limited, naturally involves considerable error. When the loss in weight is considerable, it is possible to obtain a rough measurement of the relative loss in weight. A physical examination of P.O.J. 36–M stored in the open showed that the degree of shriveling of the top joints, in the order of the greatest to the least, was as follows: Unsprinkled unstripped, unsprinkled stripped, sprinkled unstripped, and sprinkled stripped. The loss in weight, the increase in Brix, and the drop in purity (table 8) follow the same order. The difference in shriveling was not as clearly defined in the case of Co. 281. The drop in purity increases in the following order: Sprinkled stripped, unsprinkled stripped, sprinkled unstripped, and unsprinkled unstripped. The increase in Brix, which is also a measure of the loss in weight (water), is in the same order as the drop in purity, but the weight losses do not entirely correspond. It is believed that this discrepancy is due to the method of obtaining weight losses in unstripped cane, which, as already pointed out, may be in considerable error.

[12] The major portion of the loss in weight is assumed to be due to the loss in moisture.

TABLE 8.—*Brix, apparent sucrose, apparent purity, weight loss, and extraction in stripped and unstripped sugarcane stored (1) under controlled temperature and relative humidity and (2) in the open, sprinkled and unsprinkled*

Kind of storage and variety	Date of analysis	Duration of storage	Temperature (° F.) and relative humidity (percent) or treatment	Stripped				
				Brix	Sucrose	Purity	Weight loss	Extraction
Cane stored under controlled temperature and relative humidity:	1932	*Days*		°	*Percent*	*Percent*	*Percent*	*Percent*
P.O.J. 36–M (second-year stubble).	Nov. 11	0		14.94	11.47	76.8		61
	Nov. 17	6	65°; 96 percent	14.83	11.19	75.5		62
	do	6	65°; 75 percent	15.66	10.41	66.5		61
Cane stored on racks in the open:	1933							
P.O.J. 36–M (first-year stubble).	Nov. 10	0		15.57	12.21	78.4		58
	Nov. 17	7	Sprinkled	15.76	11.83	75.1	2.1	53
	do	7	Unsprinkled	16.87	9.25	54.8	8.4	58
Co. 281 (first-year stubble).	Dec. 13	0		16.93	14.23	84.1		59
	Dec. 20	7	Sprinkled	17.14	14.24	83.1	1.7	59
	do	7	Unsprinkled	17.61	14.27	81.0	3.9	60

Kind of storage and variety	Date of analysis	Duration of storage	Temperature (° F.) and relative humidity (percent) or treatment	Unstripped				
				Brix	Sucrose	Purity	Weight loss	Extraction
Cane stored under controlled temperature and relative humidity:	1932	*Days*		°	*Percent*	*Percent*	*Percent*	*Percent*
P.O.J. 36–M (second-year stubble).	Nov. 11	0		14.94	11.47	76.8		61
	Nov. 17	6	65°; 96 percent	15.12	11.43	75.6		59
	do	6	65°; 75 percent	15.50	10.45	67.4		60
Cane stored on racks in the open:	1933							
P.O.J. 36–M (first-year stubble).	Nov. 10	0		15.57	12.21	78.4		58
	Nov. 17	7	Sprinkled	16.57	10.23	61.7	6.2	57
	do	7	Unsprinkled	17.78	8.15	45.8	10.5	57
Co. 281 (first-year stubble).	Dec. 13	0		16.93	14.23	84.1		59
	Dec. 20	7	Sprinkled	17.64	14.22	80.6	1.0	59
	do	7	Unsprinkled	18.05	13.58	75.2	5.9	60

If the evaporation of moisture is held in check by storing the samples at 65° F. and 96 percent relative humidity, little inversion of sucrose in either stripped or unstripped cane occurs even in a susceptible variety like P.O.J. 36–M. If, however, the cane is stored under conditions (65° and 75 percent relative humidity) that favor evaporation, considerable inversion takes place. There was not much difference in the purity of stripped and unstripped cane at either condition of storage. This may be explained by the fact that evaporation was restricted from the tops, because in order to place the samples crosswise in the rooms it was necessary to bend the leaves somewhat and to pile the samples together, i.e., each lot of stripped and of unstripped cane. They were not spread out as were those stored in the open.

These results confirm those obtained by Browne and Blouin (*8*) in showing greater inversion in unstripped (or untopped) cane stored in the open. The cane in the present experiments was subjected to greater exposure, as Browne and Blouin were studying windrowed cane and the length of storage was different in the two cases (7 days in these experiments, a month in those of Browne and Blouin).

Alvarez (*1*) claims that this relation does not hold for P.O.J. 36 and P.O.J. 213. The discrepancy in results may be due to difference in the varieties used, as well as the difference in the environmental conditions under which the experiments were conducted, and from the fact that in the experiment conducted by Alvarez the unstripped cane was cleaned of all the leaves except the tops. The environmental conditions under which these workers (*1*, *8*) conducted their experiments are not given. However, it is believed that the loss in moisture, rather than the movement of invertase from the leaves down into the stalks, brings about a physiological condition within the stalks themselves that is responsible for the greater inversion of sucrose in unstripped than in stripped cane. When stripped and unstripped canes are stored in the open under conditions favoring rapid loss of moisture, it is to be expected that there would be more rapid loss of moisture from the unstripped than from the stripped cane, because of the greater evaporating surface of the leaves of unstripped cane, which would draw heavily on water in the stalks.

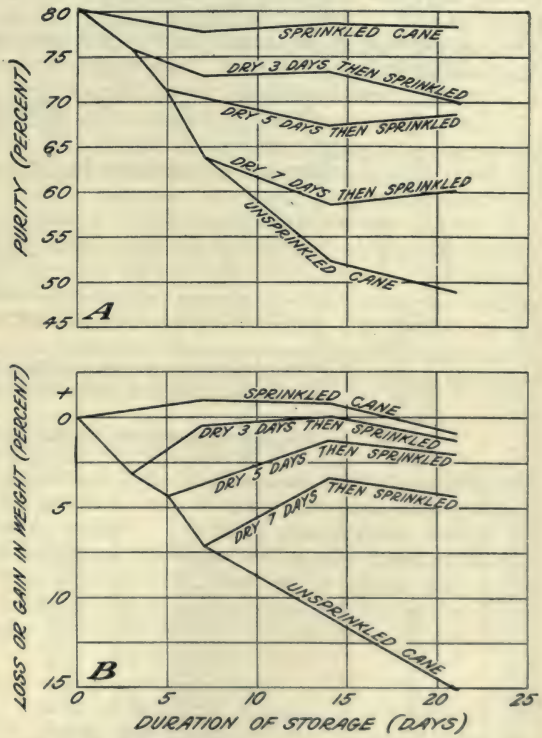

FIGURE 7.—Periodic change in purity (*A*), as related to gain and loss of weight (*B*), in 5 lots of cane (P.O.J. 36–M, first-year stubble) stored in the shade, 1 lot sprinkled, 1 unsprinkled, and the 3 others stored dry 3, 5, and 7 days, respectively, and then sprinkled.

INFLUENCE OF SPRINKLING ON CHECKING DETERIORATION RESULTING FROM PRELIMINARY DRYING OF MILL CANE

An experiment was conducted in which 30-stalk samples of P.O.J. 36–M were selected by drawing stalks at random from a large pile of uniform, freshly harvested cane. All samples were stored in the shade. One lot of samples was sprinkled, one left unsprinkled, and one each of three lots stored dry for 3, 5, and 7 days, respectively, and then sprinkled. The sprinkling was done at 7, 9, and 11 a.m. and at 1, 3, and 5 p.m. daily. The samples were weighed before storing and at intervals thereafter, in order to study the weight losses and gains. Periodic analyses were made to study the course of inversion and other changes (table 9; fig. 7). Five 30-stalk samples were used as a unit for analysis for each treatment and period of storage. The weather conditions during the period in which the

TABLE 9.—*Periodic analysis and weight gains and losses in sprinkled and unsprinkled sugarcane (P.O.J. 36–M, first-year stubble) stored for 21 days in the shade and in sugarcane stored in the shade for 3, 5, and 7 days and then sprinkled 18, 16, and 14 days, respectively, 1933*

Date of analysis	Duration of storage	Treatment of cane	Brix	Apparent sucrose	Apparent purity	Gain (+) or loss (−) in weight	Extraction	pH	Acidity [1] (0.1 N NaOH per 10 cc of juice)	Dry substance	True purity	Invert sugars	Ash	Organic non-sugars
	Days		°	*Percent*	*Percent*	*Percent*	*Percent*		*Cc*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Nov. 10	0	Check	15.77	12.68	80.4		55	5.30	1.28	15.24	85.58	8.06	2.85	3.53
Nov. 17	7	Sprinkled	15.31	11.98	78.3	+0.99	52							
Nov. 24	14	do	15.14	11.91	78.7	+.75	61							
Dec. 1	21	do	15.21	11.89	78.2	−.71	60	5.37	1.18	14.67	84.12	8.47	3.12	4.29
Nov. 10	0	Check	15.77	12.68	80.4		55	5.30	1.28	15.24	85.58	8.06	2.85	3.53
Nov. 13	3	Stored dry 3 days	16.19	12.29	75.9	−3.21	57	5.28	1.33	15.67	81.94	11.08	2.87	4.11
Nov. 17	7	Stored dry 3 days, then sprinkled 4 days	15.67	11.43	72.9	−.48	53							
Nov. 24	14	Stored dry 3 days, then sprinkled 11 days	15.22	11.16	73.3	+.04	61							
Dec. 1	21	Stored dry 3 days, then sprinkled 18 days	15.04	10.51	69.9	−1.29	60	5.37	1.24	14.55	77.46	14.36	3.23	4.95
Nov. 10	0	Check	15.77	12.68	80.4		55							
Nov. 15	5	Stored dry 5 days	16.41	11.69	71.2	−4.42	56							
Nov. 24	14	Stored dry 5 days, then sprinkled 9 days	15.53	10.45	67.3	−1.28	61							
Dec. 1	21	Stored dry 5 days, then sprinkled 16 days	15.25	10.45	68.5	−2.11	60							
Nov. 10	0	Check	15.77	12.68	80.4		55	5.30	1.28	15.24	85.58	8.06	2.85	3.53
Nov. 17	7	Stored dry 7 days	16.59	10.58	63.8	−6.95	59	5.32	1.34	16.18	71.45	21.27	3.01	4.27
Nov. 24	14	Stored dry 7 days, then sprinkled 7 days	15.80	9.26	58.6	−3.48	59							
Dec. 1	21	Stored dry 7 days, then sprinkled 14 days	15.52	9.33	60.1	−4.46	60	5.32	1.33	14.99	69.51	22.56	3.29	4.64
Nov. 10	0	Check	15.77	12.68	80.4		55	5.30	1.28	15.24	85.58	8.06	2.85	3.53
Nov. 13	3	Stored dry	16.19	12.29	75.9	−3.20	57	5.28	1.33	15.67	81.94	11.08	2.87	4.11
Nov. 15	5	do	16.41	11.69	71.2	−4.42	56							
Nov. 17	7	do	16.59	10.58	63.8	−6.95	59	5.32	1.34	16.18	71.45	21.27	3.01	4.27
Nov. 24	14	do	17.21	8.99	52.2	−11.16	58							
Dec. 1	21	do	17.66	8.62	48.8	−15.12	56	5.24	1.52	17.23	59.95	31.95	3.07	5.03

[1] Acidity determined electrometrically, employing quinhydrone electrode and titrating 50 cc juice to a pH of 7.0.

experiment was conducted are shown in figure 1 (experiment 2, 1933).

The apparent and true purity of the sprinkled cane were maintained at a high level, whereas in the unsprinkled cane they dropped rapidly with the continuation of storage. The rate in drop in purity is very definitely correlated with the increased loss in weight. The Brix of the juice from the sprinkled cane decreased gradually during the first 14 days, apparently, in response to the increased weight or absorption of moisture and then increased with the loss in weight that followed. The Brix of the juice increased in cane stored in the absence of sprinkling, but decreased when moisture was added, as did the weight loss. The invert sugar increased with the drop in purity, and there was no significant change in pH or acidity. The results in tables 8 and 9 show that the loss of moisture is an important factor in bringing about inversion in sugarcane. Taken together with unpublished data, they show it is usually more important than temperature under Louisiana conditions, at least within certain time limits.

The foregoing results indicate that inversion of sucrose in harvested cane can be checked by sprinkling after it has started, but there is a suggestion in the data that by delaying the sprinkling inversion is not quite so effectively checked as when sprinkled at the start. The results from two other experiments (not published) also confirm these in showing that sprinkling will check inversion once it has started. There can be no possible advantage, however, in delaying sprinkling, since sprinkling at the start conserves more sugar. It should be emphasized that in order to preserve the greatest possible amount of sugar, the cane should be brought promptly to the mill or the storage pile after cutting.

TESTS BY FACTORY MANAGERS

During the grinding season of 1933 all the cane (about 20,000 tons) that was transported by truck to one factory for week-end grinding was sprinkled once or twice a day. The piles varied from 200 or 300 to 2,000 tons. In some instances the cane was in the yard as long as 2 weeks. A record of the regular mill analysis in which the stored cane was compared with the analysis of the cane that was ground as it was brought to the factory indicates that there was little deterioration in the stored cane.

A rather satisfactory test involving about 1,000 tons of cane, sprinkled at 10 a.m. and 2 p.m. each day of storage, was carried out at one factory [13] from which the results given in table 10 were obtained. The cane was transported to the factory in barges within 24 hours after it was loaded, and it is estimated that all the cane was placed in the barge within 48 hours after it was cut. A barge contains about 100 tons of cane. As the cane was piled in the mill yard, three grabs of about 2,400 pounds each, one from each end and one from the center of each barge, were taken from the top, middle, and bottom portions of the barge and analyzed as a check. The percentage of sucrose given for each date of piling is the average obtained from these barge samples. The final analyses were taken from juice obtained during the grinding of the pile. The time the cane was in the pile varied

[13] Frank L. Barker, of the Valentine Sugars, Inc., Lockport, La., conducted the test and kindly furnished the data given in table 10 and the other information relating to this test.

from 4 to 10 days. The results show that there was no significant change in the sucrose content of the cane during storage.

TABLE 10.—*Influence of sprinkling on the sucrose content in cane* [1] *stored in the mill yard in 1933*

Date of storing cane	Initial weight and analysis		Date of grinding cane	Final weight and analysis	
	Weight of cane	Sucrose (normal juice)		Weight of cane	Sucrose (normal juice)
	Tons	*Percent*		*Tons*	*Percent*
Dec. 16	[2] 107.660	12.57			
Dec. 17	400.160	12.68			
Dec. 18	361.280	12.79			
Dec. 19	52.800	13.25	Dec. 24	727.370	12.54
Dec. 20	51.180	12.40	Dec. 26	245.615	12.80
Total or average	973.080	12.72		972.985	12.61

[1] About 70 percent of the cane was P.O.J. 36–M, 20 percent P.O.J. 234, and 10 percent P.O.J. 213.
[2] The initial weights were obtained at the field derricks before the cane was loaded on the barges and the final weights were obtained at the factory just before grinding.

SOME PRACTICAL CONSIDERATIONS

The results from the experiments conducted by the writers, as well as the mill-yard tests made by the plantation managers, show that mill cane, if sprinkled, can be stored in piles of considerable size for limited periods, with profit. The length of time that cane can be stored in large piles will depend somewhat on the temperature prevailing at the time and the degree of sprinkling. If the temperatures are too high and prolonged (around 70° F. and above in the piles) and there is excessive sprinkling, the cane will tend to root and later sprout. Normally, however, such temperatures do not prevail much of the time in Louisiana during the grinding season. By comparing the temperature at the center of the piles with air temperatures (fig. 5) it will be seen that the air temperatures may go considerably higher than 70° during the daytime without raising the temperature within the pile to 70°. It is believed that piles of cane of considerable size can be stored successfully for a week to 10 days by sprinkling only 2 or 3 times a day. Once the pile is thoroughly wet it is believed that all that is necessary thereafter is to wet the surface cane occasionally. By means of fine spray from a nozzle or a sprinkling system, it would be possible to limit the amount of water used, thus reducing the hazard of oversprinkling and the consequent damage to the mill yard or other place of storage.

The sprinkling of cane brought to the mills in barges and standard-gage railroad cars would likewise conserve considerable sugar, especially when the cane is transported long distances or held at or near the factory for an appreciable period before being ground. In the case of the barges, a pump could be attached to a barge and the cane sprinkled from the bayou. An overhead sprinkling arrangement, under which the cars could be run, could be used to sprinkle cane held in railroad cars.

Aside from being stored in the mill yard, cane might profitably be stored at derricks in the fields, where water and the necessary transportation facilities are readily available. Such storage would have

the advantage (1) of relieving congestion at the mill yard and (2) of enabling the plantations to store more cane when necessary to insure continuous mill operation. This cane could be picked up by grabs when railroad cars, of either narrow or standard gage, are used for transporting the cane or left in chains when the cane is transferred by trucks.

Aside from storing cane for grinding during rainy weather, it will be found profitable to sprinkle the cane now stored on the mill yard for normal week-end operations.

It should be emphasized that cane designated for storage should be stored and sprinkled as promptly as possible after it is cut, to avoid drying out and the consequent loss of sugar.

It may be possible, too, sometime in the future, to devise a simple and cheap means of providing shade and thus further protect against loss of sucrose in storage.

It is realized that in some instances the sprinkling of cane complicates the matter of obtaining the necessary weight values on which to base the pay of the grower for his cane. It is believed, however, that this question can be worked out satisfactorily between the mill manager and the grower.

Further tests will be required in connection with storage of cane in large piles to determine more accurately the frequency and amount of sprinkling required, the size of pile, and the length of time that cane can profitably be stored.

SUMMARY

The data presented deal with (1) inversion of sucrose and other chemical changes in small piles (about 1,500 to 1,800 pounds) of cane of different varieties, sprinkled and unsprinkled and stored in the shade and in the open; (2) inversion and other chemical changes in sprinkled and unsprinkled piles of cane from 7 to 70 tons, and a sprinkled pile of 260 tons, stored in the open in the mill yard; (3) the influence of weather on such deterioration; (4) temperatures in piles from 1,500 pounds to 800 tons; and (5) weight losses as related to inversion of sucrose.

The results show conclusively that the sprinkling of cane in small piles prevents heavy losses of sucrose in all varieties. The storage of unsprinkled cane may result in heavy losses of sucrose by inversion. Whether there is greater or less inversion in unsprinkled cane stored in the shade than in that stored in the open depends upon cloudiness and rainfall; wet weather tends to check inversion.

The results thus far obtained show that sprinkling retards inversion in piles ranging in size from 7 to 260 tons during 6 to 10 days' storage.

The deterioration in sprinkled and unsprinkled piles of cane is primarily due to inversion of sucrose.

There was no significant change in acidity, pH, or organic nonsugars nor any change that indicated the action of micro-organisms in sprinkled or unsprinkled piles.

Sprinkling tends to lower the temperature of cane in the piles; however, the difference in the temperature of sprinkled and unsprinkled piles is believed to be insufficient to account for the difference in deterioration, which seems to result rather from the difference in turgidity of the cane. The value of sprinkling, therefore, is believed

to depend on its effectiveness in maintaining the normal turgidity of the cane throughout the storage period.

The temperature at the center of the larger piles, although lagging behind, tends to fluctuate with the air temperature, indicating that there is no progressive accumulation of the heat of respiration and of that produced by micro-organisms.

The maturity of the cane, whether related to the sucrose content or some other physiological condition, seems to be a factor in the rate of deterioration; the more mature the cane the less rapid is the deterioration.

The inversion of sucrose is intimately associated with the loss of moisture and increases with the drying out of the cane.

Co. 281 deteriorates less rapidly under all conditions of storage than the other varieties studied. P.O.J. 36–M and C.P. 807 appear to be the most susceptible to deterioration. The position of the other varieties studied (C.P. 28/19, Co. 290, P.O.J. 213, and P.O.J. 234) seems to be between these two extremes. Their exact relation to each other has not been accurately determined. The maturity of these varieties probably plays a part in this relation.

The results presented in this bulletin show that very little deterioration occurred in stored sugarcane when it was kept thoroughly wet during the period of storage. They strongly suggest the practicability of storing mill cane, if sprinkled, in the mill yard or at the derricks during fair weather as a means for insuring more continuous operations during periods of rainy weather, which interfere with or temporarily stop, harvesting. The results also indicate that shading the stored cane, especially during dry weather, tends to furnish further protection against deterioration.

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BORON IN SOILS AND IRRIGATION WATERS AND ITS EFFECT ON PLANTS

WITH PARTICULAR REFERENCE TO THE SAN JOAQUIN VALLEY OF CALIFORNIA

By

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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INTRODUCTION

NATURAL OCCURRENCE

Boron, the element that characterizes such familiar compounds as boric acid (H_3BO_3) and borax ($Na_2B_4O_7.10H_2O$), is of agricultural importance for two reasons, namely: (1) Some of it is essential to the growth of many if not all plants; (2) it is extremely toxic to a large number of plants if present in the soil solution in concentrations above a few parts per million.

In nature, boron is never found in the uncombined or elemental state, but occurs in the form of boric acid or more commonly as borates, especially in regions that are or have been volcanic. It is not a rare element, as it is widely distributed in small amounts; but

[1] Throughout the investigation much valuable assistance and cordial support were rendered both by individuals and organizations engaged in the development and utilization of irrigation water. There is also to be especially acknowledged the cooperation of the University of California and members of the extension service. The cooperation offered by all is sincerely appreciated. The writer is further indebted to his associates in the boron investigations not only for their counsel but for many direct contributions to the investigations reported.

workable deposits of boron minerals are uncommon. According to Clarke and Washington (*10*),[2] the igneous rocks that constitute 95 percent of the 10-mile crust of the earth contain possibly 0.001 percent, or 10 parts per million, of boron. The present known boron deposits in the United States are located principally in the semiarid regions of the West. Schaller (*31*) has provided a list of "all the known boron minerals" (1929), which includes 56 names with corresponding chemical formulas. Many of these minerals are soluble in water, but the list includes 20 borosilicates, some of which are known to be practically insoluble, and the others, if soluble in the ordinary sense, are only slightly so.

In connection with the agricultural significance of this element, Kellerman (*21*) in 1920 made the suggestion that toxic concentrations of boron were likely to be found here and there in soils and irrigation waters of the southwestern United States. He pointed out that large deposits of borax and other boron minerals occur not only in several places in California and Nevada but that analyses had shown small amounts of boron in various lakes and streams.

BORON IN SOUTHERN CALIFORNIA

In 1926 and 1927 Kelley and Brown (*22*) established the fact that boron occurring as a natural constituent of irrigation water was responsible for the poor condition of certain citrus and walnut groves in southern California. The peculiar symptoms exhibited by the foliage of affected trees in Ventura County had been an object of inquiry for a number of years, and the nature of the cause was determined when citrus trees elsewhere developed similar symptoms after having been irrigated with water accidentally contaminated with the waste from packing houses in which borax was used in washing fruit. Kelley and Brown found the leaves of the Ventura County trees, as well as those adjacent to these packing houses, to contain more boron than the leaves of healthy trees. Boron occurring as a soil constituent was suspected in the Ventura County injury, and it was found that the soils of the affected groves were high in boron; but further investigation showed that in each of the several larger areas examined the boron was traceable to the irrigation water.

Investigations by the Bureau of Plant Industry following those of Kelley and Brown have confirmed their observations and have shown that boron injury was more widespread than was at first suspected. Scofield and Wilcox (*33*) have reported on the boron situation in southern California, and in addition to discussing general aspects of the problem they further described the effects of boron on citrus and walnuts. As reported by them, instances of injurious effects resulting from toxic concentrations of boron in irrigation waters occur in the following southern California localities: (1) The valley of the Santa Clara River, in Ventura County, where boron is brought in chiefly by Piru and Sespe Creeks; (2) the Simi Valley, also in Ventura County, where the boron occurs in underground waters that are pumped for irrigation; (3) the San Fernando Valley, in Los Angeles County, where boron occurs in the waters brought in through the Los Angeles Aqueduct from Owens River; (4) the vicinity of San Bernardino, where boron occurs in the waters of Arrowhead Hot Springs and in a few wells; and (5) the coastal plain in southern Orange County,

[2] Italic numbers in parentheses refer to Literature Cited, p. 129.

where boron occurs in some of the underground waters pumped for irrigation. Boron is likewise now known to occur in injurious concentrations in wells in a number of other locations in the area south of the Tehachapi Mountains.

BORON ELSEWHERE IN THE WEST

Significant concentrations of boron are quite commonly found in the underground and surface waters of that portion of the San Joaquin Valley lying west of the valley axis, and in a number of small areas near Bakersfield. Injurious concentrations are likewise found in some of the wells and streams draining to the westward in the coastal mountains and valleys, and these mountains presumably have been, in part at least, the source of the boron found along the western side of the San Joaquin Valley. The principal instance of injury to the west of the San Joaquin Valley is in the vicinity of Hollister, where high concentrations of boron are sometimes found in well waters. Boron has been found in irrigation waters in the western Sacramento Valley in an area about and below Cache Creek. It occurs also in water supplies in and about the Death Valley area and occasionally southward in the Mojave Desert. It is also found in many domestic wells in the Newlands Reclamation Project of Nevada. Other isolated instances of boron injury have been found, and it may be suspected wherever irrigation water is used if symptoms of the boron type develop.

All irrigation waters examined during the course of the investigations by the Bureau of Plant Industry have contained at least a trace of boron. Higher concentrations of boron can normally be expected in both surface and underground waters, as well as in the soil solutions, in the western arid portions of the United States than in eastern more humid regions, by reason of the higher precipitation in the eastern regions.

NATURE OF THE BORON PROBLEM

The fact that boron is now looked upon as essential to the growth of many plants furnishes fairly conclusive evidence of its widespread distribution in agricultural soils. While it is with boron as a toxic element that this bulletin is principally concerned, the boron requirements of crop plants constitutes an important aspect of the relation of the element to agriculture. Some plants are known to be benefited by concentrations of boron sufficiently high to injure others. The spread between beneficial and toxic concentrations is for some plants narrow; in fact, concentrations that stimulate vegetative development may at the same time be sufficient to produce mild evidence of injury as the older leaves mature. The variation in boron requirements and the differential toxicity of this element even to closely related plants causes the two phases of its effects on plant life to be closely allied. It is highly probable that numerous plants are found at their best only on particular soils or in particular localities because of the narrow range of boron concentrations to which they are adapted. In some localities only plants relatively tolerant to boron are successfully produced, though their selection has been by a process of trial and error without knowledge of the reason for their adaptability. As knowledge of the function in growth and mode of injury of boron is amplified by additional information and more becomes known of its

distribution in nature, changes in the choice of economic plants for certain areas are almost certain to follow. The concentration of boron required for normal plant growth and the concentrations that cause injury are of a distinctly lower order than are those of many nutritive elements and the common toxic salts.

If soils are high in naturally occurring boron and for that reason are unsuitable for certain types of agriculture, a recognition of the fact should become possible before extensive development of such lands has taken place. The concentrations of boron in the irrigation waters in the area under consideration in the San Joaquin Valley are for the most part not sufficiently high to be directly toxic to many plants, but their continued use has frequently resulted in depressed yields and in the appearance of leaf symptoms characteristic of the injury. This development of toxic effects results from the concentration of boron in the soil solution by transpiration and evaporation.

Boron applied in irrigation water tends to accumulate in the soil, and ill effects may appear only after a number of seasons and after investments have been made in permanent plantings or in the installation of expensive pumping equipment and irrigation systems. In one instance an investment reported to have been in excess of $5,000,000 was made in the development of a fruit ranch which during its first years gave promise of success. These fruit plantings were later abandoned, and the present known facts indicate that the failure is attributable to unsatisfactory irrigation water, high in boron and with sodium as the predominating base. Other examples of this sort are also to be found in which failure might have been avoided if information concerning the distribution and toxicity of boron had been available. The boron content of irrigation water has come to be regarded as having greater economic significance than the initial boron content of soils. Over much of the area considered, water of suitable quality is far more limited than are arable soils.

EFFECTS OF BORON ON PLANT GROWTH

CHARACTERISTICS OF BORON DEFICIENCY

The evidence available as to the role of boron in plant nutrition has shown that this element, at least in very low concentrations, is as essential to the development of many plants as are calcium, magnesium, potassium, nitrogen, phosphorus, sulphur, or iron. The requirement of plants for boron is in some instances so small that enough or nearly enough is supplied in the form of impurities in the so-called chemically pure salts used in making up culture solutions. Work by the writer and his associates now in progress at the Rubidoux Laboratory, Riverside, Calif., is showing that the growth and production of a number of common plants is increased by boron concentrations sufficiently high to injure other species of plants that are particularly sensitive to it.

When boron is highly deficient, the younger leaves and growing points of plants are usually affected first. The apices may die back, or the terminal buds, if not killed, may become dormant. This may be followed by the development of numerous branches which in turn may make only limited growth. As is illustrated in plate 1, the leaves of boron-deficient grapes are reduced in size and become irregularly chlorotic, with the subsequent development of small areas of dead

tissue followed by premature abscission. In some plants an arrested or retarded development of the veins takes place, resulting in a buckling of the mesophyll and in irregularities in the shape of the leaves. In citrus plants, as was first shown by Haas (*16*), the leaf veins become conspicuous and split open and there is a subsequent protrusion of corky tissue. In the writer's experiments, the apical portions of the roots are often enlarged and stubby and fail to elongate normally. Sommer and Sorokin (*37*) have shown that boron deficiency in other plants results in a deformed or lacking root cap and in a marked hyperplasia of the sterome and a hypertrophy of the surrounding periblem tissue. Warington (*40*) found the cells of the cambium to be adversely affected, this condition being followed by degeneration and disintegration of surrounding tissue. A number of investigators (*7*, *20*, *25*, *26*, *36*, *39*), have demonstrated that various plants require boron and have described the plant reactions when the supply was deficient.

The symptoms of boron deficiency nearly always make their appearance only when the available boron is considerably below the concentration required for the best growth of the plants. In other words, the absence of deficiency symptoms does not provide evidence that the plant is obtaining as much boron as might be used beneficially. Some plants develop deficiency symptoms only when special precautions have been taken to reduce the boron supply to a minimum by the use of boron-free culture vessels and repurified chemicals.

It may be recalled that during and following the World War boron toxicity became a problem of economic concern in certain Eastern and Southern States as a result of the use of fertilizers containing borax as an impurity. Investigations of borax injury resulting from fertilizers, by the United States Department of Agriculture and a number of State experiment stations (*8*, *28*, *34*), showed that injurious effects sometimes followed field applications of the equivalent of 10 pounds or less of anhydrous borax per acre. Smaller applications did not generally result in notable or clear-cut increases in yield. The lack of evidence of beneficial results from smaller applications does not, however, warrant the conclusion that the use of borax as a fertilizer, on particular soils or for particular crops, might not be profitable. In the experiments just mentioned the borax was applied in or broadcast above the drill rows at or near the time of planting, and borax thus concentrated in restricted portions of the root zone would be expected to produce injurious rather than beneficial results until it had become more uniformly distributed through the soil. Certain crops, such as figs, cotton, grapes, alfalfa, beets, and asparagus in the experiments at Riverside, Calif., by the Bureau of Plant Industry, have shown definite requirements for boron in excess of concentrations ordinarily designated as traces.

CHARACTERISTICS OF BORON INJURY

The toxic effect of boron on plants was observed and recorded as early as 1876 by Peligot (*29*), who mentions that the leaves of beans yellowed and fell from plants prematurely. Hotter (*19*), in 1890, called attention to the spotting and yellowing of leaves caused by boron. Subsequent investigations by Agulhon (*1*), Brenchley (*6*), Haselhoff (*17*), Warington (*39*), Collings (*11*), and others have all

demonstrated the highly toxic character of the element to many species of plants and have added to the fund of knowledge on the subject.

The injury produced by boron, as contrasted with the injury produced by other substances, is distinctive in its effects upon plant foliage. The typical boron symptoms are at once striking and in many cases clearly distinguishable from those normal to maturation processes or resulting from excesses of other elements of the soil solution. The fact that an excessive amount of boron in the soil solution is indicated by leaf characteristics of numerous plants, particularly during the late summer and autumn, makes it possible to arrive at fairly accurate conclusions concerning such occurrence in advance of chemical analyses of the soil, the irrigation water, or plant foliage. Wherever dooryard plants are grown, the indications afforded by their foliage are a great aid in the location of the general boundaries of boron-contaminated areas; and if the boron originates in water from wells, plant symptoms are an aid in the selection of samples for the determination of the water sources or strata most heavily impregnated. The presence of boron in toxic concentrations in certain areas of the San Joaquin Valley was originally discovered by noting plant symptoms. The fact that these symptoms are absent in extensive areas of the San Joaquin Valley has made unnecessary the collection, in such sections, of other than occasional samples of waters which have verified the plant evidence.

There is a tendency for plants to concentrate boron in their leaves, and these organs are typically the first to exhibit its injurious effects. Some variability is shown by different plants, in the character of both the initial and the later symptoms; but usually the apical margins of the leaves first turn yellow, and the yellowing then extends between the lateral veins toward the midveins. The chlorophyll of tissue towards the center and base of the leaves and adjacent to the veins is usually retained until the leaves have dropped from the plants. Areas of dead tissue develop as yellowing progresses. In some plants the dead tissue is confined to the margins of the leaves, while in others, such as walnut, sycamore, cotton, and bean, dead spots develop between the lateral veins either with or without notable yellowing in advance. These dead areas are largest and may coalesce near the periphery of the leaf (pls. 1 and 2).

In citrus and some other plants the injurious effects of boron do not make their appearance until the leaves have approached or attained full size, and the configuration of such leaves is therefore not changed. The injury to some other plants, such as grapes, tomatoes, beets, persimmons, and beans, may become apparent while the leaves are young. Such leaves do not attain a normal size, and, either with or without marked yellowing and drying, they sometimes become cupped owing to a cessation of marginal growth in advance of that of the more central portions. The older leaves are usually the first to show injury, and they abscise sooner than leaves of similar age on uninjured plants. Some of the variations of the form of injury to grapes are shown in group *C* of plate 1. The leaf on the left shows the common marginal injury with dark, discolored areas between the leaf veins. The young leaf in the center, which was spread out for the photograph, was deeply cupped, whereas the leaf at the right showed both cupping and marginal injury. All these leaves were taken from the same plant on the same day.

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LEAVES OF SULTANINA (THOMPSON SEEDLESS) GRAPES FROM RUBIDOUX EXPERIMENT 11 (1930), GROWN IN SAND SUPPLIED WITH NUTRIENT SOLUTION.

A, Boron-deficiency symptoms in leaves from plants supplied with solution having 0.05 p.p.m. of boron derived from impurities; *B*, normal leaves from plants supplied with solution containing 1 p.p.m. of boron; *C*, injured leaves from a plant supplied with solution containing 5 p.p.m. of boron.

LEAVES OF PERSIAN (ENGLISH) WALNUT SHOWING TYPE OF BORON INJURY TYPICAL OF THIS PLANT AND MANY OTHERS.

BRANCH OF AN APRICOT TREE SEVERELY INJURED BY BORON.
Note enlarged nodes and gumming.

TWIGS FROM A PRUNE TREE INJURED BY BORON.

The gumming and enlarged nodes of the twig on the right are to be noted. The bark has been removed from the other twig to show the excessive growth of wood at the nodes.

Cereals and other monocotyledonous plants show pronounced abnormalities when supplied with toxic concentrations of boron, but the symptoms, unless they are severe, cannot be differentiated with certainty from effects attributable to other causes, such as salt and normal maturation. The tips of these leaves turn yellow or brown and die back, and in corn the older leaf blades may develop yellow stripes. Barley leaves not uncommonly develop yellow and dead spots back of the burned areas. The tips of onions likewise burn, as do those of some other plants grown from bulbs. Gladiolus and palms show similar symptoms.

The stone fruits, as well as apples and pears, are sensitive to boron, but these plants do not develop in other than exceptional cases the type of symptoms that in many plants is so nearly specific. Not only are the characteristic leaf markings commonly absent, but repeated analyses have consistently shown the boron content of the leaves to be much lower than the concentrations that are built up in the leaves of such plants as walnuts and lemons.

Prunes and apricots under high-boron conditions sometimes develop growth abnormalities which, while not as specific as is the typical boron leaf injury, are nevertheless highly indicative and when taken together provide a fairly reliable basis for field diagnosis. The most outstanding of these characteristics is a peculiar enlargement of the bark of the smaller branches just below the nodes (pl. 3). The wood at the nodes is likewise found to be enlarged when the bark is scraped away (pl. 4). Accompanying this hypertrophy at the nodes there is commonly an extrusion of gum above the axes of the twigs and leaves. Both with and without these symptoms the tips of twigs often die back, and not infrequently the terminal leaves, instead of attaining normal size, remain small and often cupped, and some of them may abscise leaving vacant nodes. Another effect of boron, which has been seen in young prunes, is a tendency for the tips of the main stem and important branches to become enlarged by the formation of many closely set and poorly developed scale-bearing nodes. Late in the season short and similarly multiple-budded branches may be pushed out from these. Boron-affected apricot, and to a lesser extent prune, orchards present the general aspect of being wilted, owing to a tendency for the leaves to droop. The leaves of these trees thicken considerably when injured and, if folded and pressed lightly between the thumb and forefinger, tend to crack open at the fold.

Symptoms adequate for the field diagnosis of boron injury of peaches have not as yet been found, but in experimental cultures and in a few cases of advanced field injury a tendency for the bark of twigs above some of the leaf axes to turn brown and split open, either with or without the extrusion of gum, has been noted. Often the bark injury encircles the twig and causes death of the growth above. When injury is sufficiently severe in peaches the leaves may die irregularly along a narrow margin with an accompanying or preceding cupping of the leaf. The breaking of the restricted margins gives such leaves a ragged appearance.

Symptoms on pear and apple adequate for field diagnosis are not known.

In all of the stone fruits growth is depressed by boron concentrations below those required for the development of clearly defined symptoms.

Smith and Thomas (*35*) designate as exanthema a growth abnormality of prunes near Santa Cruz, which was remedied by applications of copper sulphate. Enlarged nodes not wholly unlike those here illustrated were among the symptoms, but the general aspect of the affected trees was very different from that produced by boron.

RELATIVE TOLERANCE OF CROPS

A wide variability exists in respect to the amount of boron that different crop plants are able to withstand, and, as was previously noted, some are benefited by boron concentrations high enough to injure the more sensitive plants. A large body of information on comparative plant tolerance is now at hand at the Rubidoux Laboratory. A detailed presentation of these data cannot be attempted in this bulletin, but it is nevertheless desirable that the subject should be dealt with briefly. An irrigation water relatively high in boron may sometimes be used profitably for tolerant crops and be entirely unsuited for crops that are sensitive. In fact, farmers using water high in boron have in some instances found, by trial and error and without knowledge of the cause, that certain crops were more suitable to their particular conditions than others.

In undertaking to determine in a careful way the boron requirements and the relative boron tolerances of some of the more common field, garden, and dooryard plants, it was considered essential that the methods employed should assure the greatest comparability in the conditions under which the test plants were grown. Soils are not only capable of absorbing boron salts or rendering them partially insoluble, but under field conditions soils are notably variable, not only from place to place but in their different horizons. For these reasons pure quartz sand was used in place of soil in this experimental work. The sand was placed in large metal beds (*13*) so arranged that it could be flooded and drained daily with solutions containing all essential plant-food elements, and for the several beds different concentrations of boron. The used solutions were replaced by new solutions at frequent intervals, and a portion of the transpiration loss was made up daily by adding water to the nutrient solution to maintain the initial boron concentrations. These procedures insured that all plant varieties grown together in any bed were subjected to like conditions with respect to the boron content of the nutrient solution with which they were supplied and that the desired boron concentrations were maintained in the different beds. The nutrient solution employed is one that supports a vigorous vegetative growth when boron is applied in sufficient but low concentrations. This experiment will be subsequently referred to as "experiment 11."

Certain plants have been found to be particularly sensitive to boron, some to be semitolerant, and others to be highly tolerant (table 1). The plants that withstand only relatively low boron concentrations have been designated in this table as sensitive, those that show only a small or moderate decrease in growth at relatively high concentrations as tolerant, and intermediate plants as semitolerant. This division of plants into three groups serves the purpose of convenience in classifying plants, but between the groups there is no sharp line of demarcation, and frequently uncertainty exists as to whether a plant should be placed near the bottom of one group or

near the top of the next. Within the groups the aim has been to name the more sensitive plants first. In some cases the difference between successive plants of the list has been quite sharp, whereas in other cases the differences were too small or the data insufficient for final conclusions. The continuation of this work will add new plants to the list and will undoubtedly result in certain rearrangements in the order.

TABLE 1.—*Tolerance of various cultivated plants to boron, Rubidoux Laboratory, experiment 11*

[In each group the plants first named are considered as being more sensitive and the last named more tolerant]

Sensitive	Semitolerant	Tolerant
Lemon	Lima bean	Carrot.
Grapefruit	Sweetpotato	Lettuce.
Avocado	Bell pepper	Cabbage.
Orange	Tomato	Turnip.
Thornless blackberry	Pumpkin	Onion.
Apricot	Zinnia	Broad bean.
Peach	Oat	Gladiolus.
Cherry	Milo	Alfalfa.
Persimmon	Corn	Garden beet.
Kadota fig	Wheat	Mangel.
Grape (Sultanina and Malaga)	Barley	Sugar beet.
Apple	Olive	Palm (*Phoenix canariensis*).
Pear	Ragged Robin rose	Date palm (*Phoenix dactylifera*).
Plum	Field pea	Asparagus.
American elm	Radish	Athel (*Tamarix aphylla*).
Navy bean	Sweet pea	
Jerusalem artichoke	Pima cotton	
Persian (English) walnut	Acala cotton	
Black walnut	Potato	
Pecan	Sunflower (native)	

Climatic conditions have an important bearing on the concentration of boron that a plant will withstand. Many plants, including the stone fruits, grown at Riverside, Calif., withstood more boron during the cooler, more humid summer of 1929 than they did during the hotter and drier summer of 1930. A number of the garden vegetables and cover-crop plants listed, when grown during the winter months to which they are best suited, have shown higher tolerance than when planted in the spring.

There are also differences in the reactions of plants to toxic concentrations of boron. Walnuts, for example, show mild late-season leaf injury at boron concentrations so low that a question may properly exist as to whether there is actually an associated injury to the plant as a whole, and yet walnuts survive in higher concentrations than the stone fruits.

The only fig tested as yet has been the Kadota. Mission figs have been observed to grow under field conditions in situations where some of the semitolerant plants showed severe injury. It now seems probable that some of the other varieties of figs are considerably more tolerant than the Kadota.

OCCURRENCE OF BORON IN PLANTS

Agulhon's review (*1*) of the early literature on the occurrence of boron in plants records an identification of this element as early as 1857 in the seeds of a *Primula*. The next reference to similar work is recorded for the year 1879, after which there were a number of papers

relating principally to the occurrence of the element in grapes and wines. Agulhon determined by quantitative methods the concentration of boron in the ash of 27 plant species distributed through 15 families, including annual and perennial Angiosperms, Gymnosperms, Cryptogams, and marine algae. His values, when expressed as boron in the dry plant material, show a range of from 7 to 14 p.p.m. of boron, respectively, in the stems and leaves of fir trees to 79 p.p.m. in the leaves of figs. *Fucus* from the English Channel contained 168 p.p.m. of boron. Agulhon conducted a number of plant experiments both with nutrient solutions and in the field, but in only one instance did he report the effects of the treatments on the boron content of plants grown experimentally. As reported by Scofield and Wilcox (*33*), the boron content of leaf samples of citrus plants collected in Florida ranged from 31 to 161 p.p.m. and at Silver Hill, Ala., from 55 to 132. Leaves of post oak, sassafras, and wild grape from Maryland contained 35, 59, and 51 p.p.m. of boron, respectively. A range from 61 to 177 p.p.m. was found in the boron content of 6 samples of citrus leaves from the valley of the lower Rio Grande at Weslaco, Tex. The results taken collectively constitute evidence that boron at least in small amounts is widely distributed and is probably a constituent of all agricultural soils.

The boron content of 127 scattered samples (*33*, *table 2*) of citrus and walnut leaves collected in southern California ranged from 35 to 1,522 p.p.m. The boron content of the mature leaves of these plants when no injury was apparent was generally less than 300 p.p.m., and when definitely injured, in excess of 400 or 500; concentrations between 300 and 500 p.p.m. are of uncertain significance. Instances of boron concentrations in the leaves of both citrus and walnut trees in excess of 1,000 p.p.m. on the dry-weight basis have been encountered a number of times. Notwithstanding the lack of outstanding difference in the extent of boron accumulation in the different commercial citrus varieties in California, the lemon is definitely more sensitive to boron than the orange, and the grapefruit occupies an intermediate position. Nearly all instances of high concentration of boron in the leaves of these plants in southern California have been associated with irrigation waters also relatively high in boron.

A marked diversity exists in the extent to which different plants grown under comparable conditions accumulate boron in their foliage. A few plants are known that accumulate more boron than the lemon and the walnut, but there are many that accumulate less. As an illustration of this diversity, reference is made to table 2, in which are listed the boron contents of a series of leaves collected from a small mixed orchard on a ranch southwest of Mendota, Calif. This orchard had been irrigated since it was planted from a deep well which, when sampled, contained 1.39 p.p.m. of boron. The water was somewhat saline, having a total salt content in the order of 1,300 p.p.m. Sodium was the dominant base in this water, and as a result the soil had become hard and relatively impervious. The table is not presented for the purpose of drawing conclusions as to the relative tolerance of the different trees, since factors in addition to boron in all probability were operating in the determination of adaptability. There were open places in the orchard indicating that some had already died out, and others were in poor condition; also certain of them may have been younger than others as a result of replanting.

TABLE 2.—*Boron content of leaves in a mixed orchard planting in western Fresno County, Calif.*

[Samples collected Sept. 1, 1931. Boron expressed in parts per million on dry-weight basis]

Sample no.	Variety	Boron content	Sample no.	Variety	Boron content
		Parts per million			*Parts per million*
1059	Lemon	962	1067	Loquat	60
1060	Peach	132	1068	Plum	77
1061	Persimmon	913	1069	Nectarine	143
1062	Cherry	119	1070	Apple	86
1063	Quince	50	1071	Almond	82
1064	Grape	924	1072	Pomegranate	33
1065	Fig	2,222	1073	Olive	77
1066	Cottonwood	2,018			

The fact that plants growing in or adjacent to the same plot of ground may vary to such a remarkable degree in the extent to which they accumulate boron in their leaf tissues clearly indicates outstanding physiological differences which parallel in interest the outstanding differences in the tolerances that different plants show to high boron concentrations. Lemon trees grown in nutrient solutions containing 6 p.p.m. of boron have died, whereas alfalfa, asparagus, and tamarix have been grown in solutions with 100 p.p.m. and certain native plants have been observed to grow in a soil watered by a flowing well containing 161 p.p.m. of boron.

Among the plant characteristics that might be expected to fall in the front rank of importance in the determination of tolerance are those governing either boron absorption by the plant as a whole or the accumulation of boron in particular organs. Evidence is at hand which suffices to show that the relationships in this regard are not simple, and no general criteria are known upon which to judge the tolerance of a plant variety other than by experimental tests and field observations.

In table 1 there was presented a list of plants arranged in what is believed to represent the order of their relative tolerances. Many of these plants have been grown in the sand beds for more than one season. During different seasons the relative tolerances have been found to be essentially the same when reasonable allowances are made for the variability that must necessarily accompany small populations and differences in season. Boron determinations have been made on all these plants, sometimes on composite samples of entire plants, sometimes on the roots, stems, leaves, and grain, and sometimes on the leaves only. Owing to climatic factors, the time of harvest, or the stage of growth at which the plants were harvested, the boron content of each variety has been found to vary to a moderate extent in the different plantings. Leaving the detailed discussion of these effects to another time, it is of interest to examine, among different plants, the extent of the relationship between boron tolerances and the boron concentrations built up by plants in their tissues. For the purpose of illustrating what has been found, a list of representative plants selected from experiment 11 are presented in table 3 in the order of their tolerance of boron. The plants in this experiment were all planted in a series of culture solution concentrations ranging from "0 boron"[3] to 25 p.p.m., but only the boron concentrations found in the plants of the 5 p.p.m. cultures are shown here.

[3] See p. 16.

TABLE 3.—*Boron content of plants grown in sand culture supplied with nutrient solution containing 5 p.p.m. of boron, Rubidoux Laboratory, experiment 11*

[Boron in plants expressed in parts per million on dry-weight basis]

SENSITIVE PLANTS

Sample no.	Plant		Boron content	Sample no.	Plant		Boron content
	Variety	Portion			Variety	Portion	
			P.p.m.				*P.p.m.*
1338	Lemon	Leaves	1,232	974	Sultanina grape	Leaves	1,046
1330	do	Stems and roots	54	496	Apple	do	143
494	Avocado	Leaves	569	498	Pear	do	120
929	Blackberry	do	717	817	Plum	do	92
487	Apricot	do	99	867	American elm	do	943
829	Cherry	do	182	871	do	Stem	22
484	Persimmon	do	997	781	Navy bean	Entire	648
805	Kadota fig	do	722				

SEMITOLERANT PLANTS

			P.p.m.				*P.p.m.*
775	Lima bean	Entire	515	916	Ragged Robin rose.	Leaves	220
334	Tomato	do	169				
268	Pumpkin	do	291	920	do	Stems	29
360	Sweetpotato	Tops	218	628	Field pea	Entire	207
315	Milo	Tops and roots	102	1143	Sweet pea	Leaves	520
320	do	Heads	22		do	Entire	210
325	Corn	Tops and roots	60	956	Acala cotton	Leaves	306
330	do	Grain	16	962	do	Stems and roots	32
389	Wheat	Entire	453	529	do	Entire	123
405	Barley	do	447	638	Potato	Tops	179
977	Olive	Leaves	215				

TOLERANT PLANTS

			P.p.m.				*P.p.m.*
680	Carrot	Entire	69	374	Gladiolus	Tops	253
1233	do	Leaves	124	355	Alfalfa	Entire	139
618	Lettuce	Entire	261	660	Garden beet	do	144
350	Cabbage	do	142	757	Sugar beet	Leaves	177
664	Turnip	do	245	763	do	Roots	28
1408	Onion	Tops	242	364	Asparagus	Entire	120
1202	do	Bulbs	105	950	Palm	Pinnae	279
524	Broad bean	Entire	244				

It is customary in the field to select for boron determinations only mature leaves, whereas in table 3 where the boron content of leaves is given the sample represents all leaves, both young and old, on the plants at the time of harvest. Boron concentrations usually increase in leaves as they grow older, but the boron concentrations in entire plants taken from the same crops at different stages of maturity may either increase or decrease as the plant becomes older. This is so since the woody parts of the plant as well as the roots, seed, and fruit, which contain much less boron than the leaves, constitute larger proportions of the weight of old plants than of young ones.

Table 3 indicates a strong tendency for the boron-sensitive plants to accumulate more boron in their leaves than those of either the semitolerant or the tolerant group. The same tendency applies in comparisons between the boron content of entire plants in the two latter groups. The exceptions to this tendency, however, are too numerous and some are of too great magnitude to provide on this single basis a general or adequate explanation for tolerance. Some of the notable exceptions to the tendency are among the sensitive plants. Apples, pears, and the stone fruits are found to have

relatively little boron in their leaves, whereas leaves of the lemon, blackberry, fig, grape, and elm are high in boron. In the semi-tolerant group the lima bean has more than twice as much boron as the sweetpotato, and yet their tolerances are considered as being approximately the same. Of the cereals, milo and corn have much less boron than wheat and barley, but they withstand approximately the same boron concentrations. The leaves of cotton have about 40 percent more boron at this concentration than do leaves of either the olive or the Ragged Robin rose, but cotton is more tolerant than either. In the tolerant group none of the plants so far examined are high in boron, which fact is noteworthy.

It is shown incidentally in table 3, and also previously mentioned, that boron is not uniformly distributed throughout the plant in the different organs or parts. Rooted lemon cuttings grown in experiment 11 had 1,232 p.p.m. of boron in their leaves, which varied in age from young to those ready to abscise, and only 54 p.p.m. in the trunk, stems, and roots. Similarly, young elms had 943 p.p.m. in the leaves, 22 p.p.m. in the main stem and branches, and 18 p.p.m. in the roots. Sugar beets had 177 p.p.m. in the leaves and 28 p.p.m. in the fleshy roots.

The uneven distribution of boron throughout the plant does not stop with particular parts or organs, but is carried to the different portions of the same organ. In describing boron symptoms it was observed for some plants that as injury became evident the margins of the leaves first yellowed, particularly the apical margins, and that the yellowing then progressed along the margins toward the base of the leaf and inward toward the midvein, the veins and the tissue adjacent to them remaining green for a longer time. As injury becomes pronounced, some of the tissue first yellowed commonly dies, the dead tissue remaining in place as a part of the leaf.

For the purpose of determining whether this pattern of injury was associated with the accumulation of boron respectively in the uninjured portions, the yellowed portions, and the dead portions, 150 leaves were collected from a boron-treated Eureka lemon tree at the Rubidoux Laboratory. The different portions of the leaves enumerated were carefully separated with a scalpel and dried for boron determinations. The boundary between the yellow and green areas is infrequently sharp, and there was, therefore, a little admixture of both in the yellow and green samples, but the whole of each leaf was included in one or another of each of four samples reported in table 4.

TABLE 4.—*Boron content of several portions of 150 boron-injured Eureka lemon leaves*

[Collected and dissected in December 1930. Boron expressed in parts per million on dry-weight basis]

Portion of leaves	Dry weight	Boron
	Grams	*P.p.m.*
Midveins and petioles	6.9	47
Green portions	22.6	438
Yellowed portions	7.1	1,060
Dead portions of apices and margins	4.5	1,722
Weighted mean of entire leaves		620

The differences found in the boron content of the different leaf fractions are definite and of outstanding magnitude. They indicate an intimate relationship between the injury that had taken place and the boron concentrations in the corresponding tissues.

The form in which boron occurs in the plant has not been established, and it is not known that all of it is in solution. Presumably, however, it exists in one or more of several reasonably soluble forms. Assuming that all the water [4] of these leaves acted as a solvent (a significant percentage of it does not) and that the boron was all in solution, the concentration of boron in the sap of the yellow tissues where the chlorophyll had largely disappeared was about 800 p.p.m., and the concentration in the sap of the dead tissue before death must have been about 1,300 p.p.m. The latter corresponds to the concentration of boron in a boric-acid solution 17.2 percent saturated at 20° C.

The distribution of boron in the leaves of lemon shown in table 4, conforming as it does with the pattern of injury, supports the view that boron is carried by the transpiration stream into the leaves, and that the movement of water through the cells of the leaves with the transpiration stream tends to carry it to leaf tissues farthest removed from the water vessels of the leaf veins. The distribution of boron in the various parts of the plant, as shown by the boron content of seeds, fruit, and roots (note especially the roots of the beet, table 3, in which extensive storage takes place), further indicates that little boron is translocated from the leaves with organic products in plants of this class, but tends to remain and accumulate in the leaf cells. The fact that the greatest injury occurs to tissue at points of highest boron concentration does not point to the formation or occurrence of appreciable concentrations of nontoxic or insoluble forms of boron in the plant. Boron has an affinity for certain sugars and polyhydric alcohols, and a reaction with one of the latter, mannitol, by which a hydrogen ion is liberated for each molecule of boric acid present, is the basis for the method used in boron determination. Since boron and certain of the carbohydrates are known to combine to form esters, it is quite probable that similar compounds may form in the plant, but if such is the case they are not as extensively translocated as are the uncombined photosynthetic products.

The distribution of boron in the stone fruits is quite different from that in the lemon, and the manner of injury is likewise different. Boron does not accumulate in the leaves of these to the extent that it does in many boron-sensitive plants, and, as has been stated, stone fruits rarely develop leaf symptoms characteristic of boron injury. The stone fruits may, however, develop growth abnormalities at their nodes (pls. 3 and 4) in the form of hypertrophy of both the bark and the wood, or, as in peaches, the cortex may break down. For the purpose of determining whether this overgrowth of the cortex and of the wood at the nodes was in any way associated with an accumulation of boron at these points, the separations of tissue shown in table 5 were made for boron determinations.

[4] According to results privately communicated by F. F. Halma, of the California Agricultural Experiment Station, lemon leaves normally contain 57 percent of moisture in December.

TABLE 5.—*Distribution of boron in prune and apricot twigs collected near Hollister, Calif., October 15, 1932, and, for comparison, boron in lemon twigs collected from boron-treated trees at Riverside, Calif., January 22, 1932*

[Boron expressed in parts per million on dry-weight basis]

Sample no.	Species and condition	Boron content		
		Leaves	Bark	Wood
		P.p.m.	*P.p.m.*	*P.p.m.*
1119–1121	Prune, injured	176	412	171
1125–1127	Prune, uninjured	33	36	11
1122–1124	Apricot, injured	82	206	82
1076–1078	Apricot, uninjured	52	38	23
1533–1535	Lemon, slightly injured	410	42	9

Table 5 shows boron to have accumulated in the bark and to a lesser extent in the wood of injured prune and apricot twigs and to be relatively low in the same tissues of unaffected twigs. Boron did not accumulate in the twigs and cortex of injured lemon trees. Twigs collected from other boron-injured prune trees in the same orchard in January had 388 p.p.m. of boron in the buds, 244 p.p.m. in the bark adjacent to the buds, 136 and 133 p.p.m., respectively, in the outer and inner bark of the internodes, and 46 p.p.m. in the wood. The buds from twigs of injured pears contained 183 p.p.m. of boron, the adjacent bark 143 p.p.m., the internode cortex 139 p.p.m., and the wood 122 p.p.m. The results provide a means of accounting for the high toxicity of boron to stone fruits in the absence of abnormal leaf characteristics. Studies of the nature of associated anatomical abnormalities are now in progress. The overgrowth at the nodes has clearly indicated their existence, as does the large amount of gum extruded. An examination of the extruded gum for boron showed very low concentrations.

The orchard from which the prune twigs were collected had been observed by pathologists and others prior to the recognition that boron was the cause of its poor condition, and one section of the orchard had been pulled out. Prior to 1931 the orchard was irrigated principally from a well, and a bailed sample from it contained, in September 1931, 3.98 p.p.m. of boron. During 1931 a new well carrying in excess of 15 p.p.m. was used. The conclusion that boron might be the cause of the disorder was arrived at by W. R. Schoonover, of the California station, on the basis of the appearance of adjacent walnuts. Leaves of these walnuts collected by him in August 1931 contained 1,033 p.p.m. of boron, some of the walnut trees were dying, and the others were in poor condition.

TOXICITY OF BORON

In the preceding sections it has not been directly shown that as the boron concentration of the soil solution is increased there follows an increase in the boron content of the plant tissue, nor has it been shown that with an increased concentration of boron in the plant tissue there is an accompanying effect upon the growth of the plant. Both of these effects are illustrated in table 6 with data taken from experiment 11, previously described.

TABLE 6.—*Growth and boron content of plants in sand beds supplied with nutrient solutions, experiment 11*

DRY WEIGHT OF ENTIRE PLANTS

Plant	Period of growth or part of plant	Grown with nutrient solution containing boron of indicated concentration (p.p.m.)					
		"0"	1	5	10	15	25
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Malaga grape [1]	Apr. 19 to Nov. 14, 1930	149	379	74	18	15	----
Kadota fig [1]	Apr. 2 to Nov. 12, 1930	169	456	138	10	----	----
Dwarf milo	May 22 to Sept. 19, 1929	678	----	617	419	394	204
Acala cotton	June 5 to Dec. 9, 1929	114	----	149	177	153	83
Sugar beet	Apr. 22 to Sept. 8, 1930	75	390	444	375	434	379
Palm [2]	May 1929 to Nov. 1930	150	----	382	420	402	401

BORON CONTENT OF INDICATED PART OF PLANT (ON DRY-WEIGHT BASIS)

		P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*
Malaga grape	Leaves	38	250	926	1,774	----	----
Kadota fig	do	15	404	722	1,296	----	----
Dwarf milo	Less heads	17	----	102	208	292	427
Acala cotton	Less seed cotton	12	----	123	312	361	536
Sugar beet	Tops	20	89	177	262	304	592
Date palm	Pinnae	9	----	279	661	959	1,980

[1] From 1-year-old rooted cuttings pruned back.
[2] *Phoenix canariensis*, 1928 seedlings.

The culture solution designated as "0 boron" contained only such boron as was introduced as an impurity with the ordinary chemically pure chemicals used in making up the base nutrient solution, that derived from the apparatus and the quartz sand, or that resulting from free exposure out of doors. Repeated analyses of the "0" culture solutions both before and after use showed that for the most part these solutions contained approximately 0.05 p.p.m. of boron. The concentration of boron in the solution supplying the other beds was maintained at or near the designated initial concentration by the daily addition of appropriate quantities of water to the culture solution to offset the concentrating effects of transpiration and evaporation. The 1-p.p.m. concentration was not included in the 1929 experiments.

All plants tested have shown higher boron concentrations in their tissues when the boron concentration of the nutrient solution was higher. The examples of table 6 are taken to illustrate plants of contrasting boron requirements and boron tolerances. The optimum range for the Malaga grape and the Kadota fig is narrow. Both respond to boron and both are sensitive. Dwarf milo has not shown definite benefits from added boron, but the plants in the "0" bed have tended to produce a greater number of tillers late in the season and to remain green after the plants supplied with boron matured. Acala cotton, both in the total weight of the plants and in the number of bolls produced, had a higher boron requirement for maximum growth than any other plant as yet studied, but cotton plants were injured by the 15- and 25-p.p.m. concentrations. Sugar beets in the "0" solution produced undersized roots with zones of disintegrated tissue; the leaves were reduced in size, with large areas of the tissues broken down, and judged by taste there was little sugar present in the pulp. The leaves of sugar beets in the higher concentrations showed some

cupping and burning, but the yield was not significantly reduced. Like the sugar beet, alfalfa is benefited when some boron is added to the culture solution, and the growth is only moderately reduced at higher concentrations. The palm (*Phoenix canariensis*) was apparently benefited by 5 p.p.m. of boron. The plant in the 25-p.p.m. culture was more compact and the pinnae were burned back about 2 inches, but no reduction in weight occurred.

Nearly all of the annual crops have shown a retarded germination rate and reduced seedling vigor in the higher concentrations of boron.

BORON IN SOILS

The relatively small number of boron determinations that have been made on soils, whether irrigated or not, have in each instance shown boron to be present. In a few cases in the San Joaquin Valley the analyses show that the boron contained in unirrigated soils has been sufficient to have an adverse effect upon crop growth or so high as to hasten the injurious effects following irrigation with water high in boron. Notwithstanding evidence of the occasional occurrence of unirrigated soils containing appreciable concentrations of soluble boron in the San Joaquin Valley, the general inference to be drawn from the appearance of crops grown under irrigation leads to the conclusion that such depression in yield or growth as may be caused by boron is attributable for the most part to boron carried by the water applied.

Boron as found in soils does not appear to be very soluble, and for that reason boron that has accumulated in the root zone is not as easily removed by leaching as are chlorides and soluble sulphates. Several lemon trees growing at the Rubidoux Laboratory at Riverside, Calif., on a soil with a moisture equivalent of about 10 percent have been irrigated by the University of California in basins since March 1926. During the period from March 1926 to May 1927 boron was added to these basins at the time of each irrigation in such quantities as to produce a concentration of 5.0 p.p.m. in the water used (*22*). In 1934 these trees still show some adverse effects of the treatment—this notwithstanding continued irrigation in the basins, subsequent to May 1927, with water containing less than 0.15 p.p.m. of boron.

The behavior of boron, or more correctly of boron compounds, in soils constitutes an important problem. It is no longer difficult to determine accurately very small quantities of boron in aqueous solution, but each method of extracting a series of test soils for such determinations has yielded different values which bear little relation one to another. Extractions with water at high temperatures yield several times as much boron as extractions at low temperatures, and variations of the water-soil ratio used for extraction give different results; also, digestions with acid materially increase the boron obtained. Almost from the beginning of the boron investigations it has been recognized that an equilibrium exists between the undissolved boron in the soil and the boron in the soil solution, and the need of suitable methods for the determination of potentially soluble boron in soils has been appreciated as essential for a full understanding of the effects of boron in irrigation waters. Irrigation waters of similar quality, for example, have been observed to produce varying degrees of injury on different soils, and the time elapsing between the first

use of a contaminated water and the first appearance of crop injury likewise varies with different soils. With heavy soils the onset of crop injury is apt to be retarded as compared with light soils. Not only do adverse effects usually become apparent sooner on light soils than on heavy soils, but when good water is substituted improvement is more rapid in the light soil.

The relationship between the boron-fixing power of soils and their texture is only a general one. It is believed that the colloidal matter of soils is the most active constituent, and heavy soils are usually higher in colloidal matter than light soils. The boron-fixing power of 4 San Fernando Valley soils has recently been examined by adding to each from 2 to 25 p.p.m. of boron as boric acid. Each of the 4 soils was wetted with three-fourths of its saturation percentage of moisture and set aside for 30 days. Two of these soils, with moisture equivalents of 5.3 and 15.1 percent, removed approximately 25 percent of the added boron from solution and 2 of them, with moisture equivalents of 13.5 and 24.6, removed approximately 50 percent of the added boron.

The factors that determine the equilibrium between the undissolved boron in the soil and the concentration of boron in the soil solution are not known, but it is recognized on limited evidence that they may be diverse. There is evidence to support the view that the solubilities and rates of formation of an undetermined series of mixed boron compounds may be of primary importance, and that soil colloids, possibly those active in base exchange, take up and render unavailable indefinite quantities of boron. Some boron minerals are highly insoluble. For example, plants grown by the writer in a tourmaline mineral (Al, Cr, Fe, B_2SiO_5) powdered to pass a 100-mesh screen developed no symptoms of boron injury.

Some soils near Hollister, Calif., show remarkable boron-fixing powers. The crops on a few have not shown conspicuous injury even when irrigated with waters containing up to 10 p.p.m. of boron for a number of years. Omund Lilleland, of the University of California, has applied as much as 60 pounds of boric acid to a heavy soil at Davis without producing injury to the prune tree that the soil supported. This amount of boric acid would be roughly equivalent to 60 p.p.m. of elemental boron in terms of the dry weight of the soil. Four ounces of boric acid, if absorbed by one of these large trees, would undoubtedly have produced serious injury. As a further illustration of the marked variability in the capacity of different soils to absorb boron, cotton was grown on a heavy soil at the United States Cotton Breeding Field Station at Greenville, Tex., which had been treated at the rate of 2,000 pounds of borax per acre, and according to Homer C. McNamara no adverse symptoms developed the first season and only a few plants showed injury during the second. But as has been noted, drill-row applications of not more than 10 pounds of anhydrous borax per acre greatly reduced cotton yields on light soils in the Southeastern States.

Evidence of the distinction that exists between the behavior of boron compounds and such ions as chlorides and readily soluble sulphates is illustrated by the data of table 7. The 10 soils there represented were chosen on the basis of soil types and field conditions. The crops grown on some showed marked boron injury, and on others evidence of boron injury was entirely absent. The diversity of soil

character is represented in part by the reported moisture equivalents. It may be noted from the boron content of the first three percolates in this table that there are marked differences in the rate at which boron is liberated from different soils to the percolating solution. Significant amounts of boron were in all cases found in the third percolates, whereas nearly all of the chlorides and sulphates were removed by the first two percolates. Sulphates persisted in the percolates of soils 9 and 10, since gypsum in excess of its solubility in the water used for leaching had been added to each. Some boron was obtained in the twentieth percolate from each soil.

TABLE 7.—*Comparison of retention of boron and of chlorides and sulphates in 10 soils when 2 kilograms of each was placed in duplicate percolator tubes and leached 3 successive times with the saturation percentage of water*

Soil, percolate, and extrac.	Moisture equivalent	Saturation percentage	Volume leaching solution per kilo of soil	Constituents		
				B	Cl	SO_4
				P.p.m.[1]	[2]	[2]
Soil 1	8.4	29.1	291			
Percolate:						
First				0.09	0.42	0.66
Second				.04	.03	.05
Third				.05	.03	T[3]
Twentieth				.003		
Total of 20				.54		
1:5–S extract [4]				.20	.65	.61
Soil 2	11.9	31.3	313			
Percolate:						
First				2.04	1.08	1.37
Second				.84	.03	.12
Third				.67	.03	T
Twentieth				.06		
Total of 20				5.89		
1:5–S extracts [4]				2.83	1.10	1.55
Soil 3	14.1	30.2	302			
Percolate:						
First				.22	.36	1.52
Second				.20	.03	.07
Third				.17	.07	.02
Twentieth				.02		
Total of 20				1.35		
1:5–S extracts [4]				.53	.30	1.33
Soil 4	11.5	28.3	283			
Percolate:						
First				.80	.47	.94
Second				.40	.03	.07
Third				.24	.06	.01
Twentieth				.04		
Total of 20				2.46		
1:5–S extracts [4]				1.22	.71	1.13
Soil 5	21.2	41.9	419			
Percolate:						
First				.29	.69	2.33
Second				.33	.06	.10
Third				.30	.06	T
Twentieth				.02		
Total of 20				1.81		
1:5–S extracts [4]				.69	.84	2.34

[1] Boron determinations referenced to dry weight of soil.
[2] Milligram equivalents per kilogram of dry soil.
[3] T = trace.
[4] 1 part of soil to 5 times saturation percentage of water.

TABLE 7.—*Comparison of retention of boron and of chlorides and sulphates in 10 soils when 2 kilograms of each was placed in duplicate percolator tubes and leached 3 successive times with the saturation percentage of water*—Continued

Soil, percolate, and extract	Moisture equivalent	Saturation percentage	Volume leaching solution per kilo of soil	Constituents		
				B	Cl	SO_4
				P.p.m.[1]	[2]	[2]
Soil 6	12.2	32.9	329			
Percolate:						
First				0.24	.44	1.87
Second				.20	.06	.11
Third				.19	.06	.03
Twentieth				.03		
Total of 20				1.36		
1:5–S extracts [3]				.56	.74	1.99
Soil 7	22.5	46.8	468			
Percolate:						
First				.28	1.24	9.27
Second				.35	.13	.72
Third				.39	.04	T [4]
Twentieth				.01		
Total of 20				2.15		
1:5–S extracts [3]				.87	1.52	9.13
Soil 8	22.3	46.5	465			
Percolate:						
First				.29	1.31	4.58
Second				.29	.07	.27
Third				.23	.07	.13
Twentieth				.01		
Total of 20				1.81		
1:5–S extracts [3]				.49	1.63	5.02
Soil 9 [5]	17.4	35.7	357			
Percolate:						
First				.19	2.89	20.63
Second				.14	.14	16.21
Third				.18	.02	15.04
Twentieth				.01		
Total of 20				1.46		
1:5–S extracts [3]				.62	3.03	65.28
Soil 10 [5]	21.3	44.3	443			
Percolate:						
First				3.82	4.93	56.12
Second				2.78	.08	26.56
Third				1.87	.04	19.68
Twentieth				.11		
Total of 20				14.42		
1:5–S extracts [3]				5.76	5.09	117.75

[1] Boron determinations referenced to dry weight of soil.
[2] Milligram equivalents per kilogram of dry soil.
[3] 1 part of soil to 5 times saturation percentage of water.
[4] T=trace.
[5] 50 and 250 milligram equivalents of $CaSO_4$ per kilo were mixed respectively with soils 9 and 10 before filling the percolation tubes and before making the 1 to 5–S extracts.

If soils are leached with water to which boron has been added, the extract obtained may be either higher or lower in boron than the leaching solution. If a considerable part of the soluble boron has been removed from a soil by leaching with boron-free water, or if a soil is initially relatively free of boron and a water with several parts per million of boron is then used, many successive leachings may be required before equilibrium results and the solutions recovered attain

substantially the concentration of boron used in the leaching solution. In other words, the concentration of boron in a leaching water and in the soil, and the soil characteristics that determine the equilibrium concentration, may cause boron to be either absorbed from or released to percolating water. When land is irrigated with boron-contaminated water the soil may remove boron from the water used and for a time maintain a soil solution with less boron than the irrigation water. On the other hand, when toxic concentrations have been reached in the soil solution it may be necessary to pass large quantities of good water through the root zone to reduce substantially the soil-solution concentration.

Two distinct measures of the boron in soils are recognized as desirable. To describe adequately the boron conditions in a soil one should be able to set forth (1) the total amount of boron looked upon as water soluble or potentially injurious and (2) the concentration of boron in the soil solution. Some doubt is entertained as to whether it will be possible to work out an entirely satisfactory method for determining the first of these values. The nature of this problem has already been made evident in the foregoing discussion of the solubilities of boron compounds and the effect of acids and temperature upon their solubilities. It is possible, however, to arrive at satisfactory values for the concentration of boron in the soil solution, and it is this concentration that is most directly reflected by crop conditions. The procedure for displacing the soil solution, nevertheless, is a difficult one and requires considerable experience. The details of the method must be varied to suit different soils, and not uncommonly retrials with variations in moisture content, degree of packing, etc., are necessary. For practical purposes recourse is now taken to what is designated as three-fourths saturation percentage extracts. This method is direct and involves little difficulty. Also much less soil is required. These extracts are obtained by wetting 500 or 1,000 g of soil with three-fourths of the saturation percentage of water and then extracting a portion of this water with air pressure after the soils have been wetted for several days. The concentrations found in the three-fourths saturation extracts are ordinarily a little lower than in displaced soil solutions. The concentrations of boron found in three-fourths saturation extracts of the 10 soils listed in table 7 were on the average 88 percent as high as in corresponding displaced soil solutions. Good correlations have been found between these values and crop conditions.

In undertaking the culture of plants in the experimental sand beds for the determination of boron tolerance, it was assumed that their reactions to the boron of the nutrient solutions held by the sand would be essentially the same as those of plants grown in soils with soil solutions of like concentrations. To the extent that it has yet been possible to make comparisons between the reactions of the plants grown in culture solutions of known boron concentrations with field plants grown on soils of determined soil solution concentrations, this assumption has been substantially verified. It is recognized nevertheless that some discrepancy must result from such factors as nitrate differences between culture and soil solutions and from soil variability.

Boron occurring naturally in toxic concentrations in unirrigated soils is not uncommonly found in small areas surrounded by produc-

tive land. The topography or the appearance of such land frequently provides no index as to either the condition or its cause, and yet the boron content of the soil of such areas may differ to the extent of more than 20 to 1 from that of adjacent land. One such area is shown by figure 1 in a peach orchard south of Tracy, Calif. Soil 10 of table 7 was taken in the foreground area, in which both the original and the replanted peach trees either died or made little growth. Soil 9 of table 7 was taken from among healthy trees shown in the background.

COUNTERACTION OF BORON AND THE USE OF BORON-CONTAMINATED WATER

It has frequently been asked whether it is possible to remove boron from irrigation water. For practical purposes it is necessary

FIGURE 1.—A small area of boron-impregnated, unproductive soil surrounded by fertile land. (Field 7, SE. ¼ sec. 31, T. 3 S., R. 7 E. July 9, 1931.)

to answer in the negative. Methods have been proposed, and in the laboratory it may be possible to render a part of the boron in a solution insoluble, but no feasible method applicable to irrigation water is known. To precipitate the few parts per million of boron in irrigation water, excessive concentrations of reactive salts would be necessary and might in themselves prove toxic. The only recommendations that can now be made are the substitution of another water, dilution by blending with better water, or the cultivation of less sensitive crops.

It has likewise been asked whether something could not be applied to the soil to reduce the toxicity of boron. Well-cared-for and well-fertilized orchards not uncommonly show less marked boron symptoms than do partly neglected groves irrigated with the same water. It has been found that the severity of the boron injury shown by lemons and grapefruit in controlled experiments both in sand and in water cultures is materially reduced when the concentration of the nitrogen supplied is increased. Field observations have likewise indicated that the liberal use of nitrogenous fertilizers reduces the severity of boron injury in citrus plantings. Potassium and sodium

supplied in relatively high concentrations have been found to modify the character but not the intensity of leaf injury caused by boron. The concentrations of chlorides, sulphates, and phosphates have not been found to affect materially the severity of boron symptoms.

When an irrigation water is high in chloride or sulphate it ought to be used in sufficient abundance to displace the soil solution by leaching as it becomes concentrated by transpiration and evaporation. The situation with respect to boron, however, is not so simple; unlike chloride, a part of the boron applied with water, instead of remaining in solution, may accumulate in the soil in an undissolved but potentially available form, and for this reason the same considerations cannot be applied to the use of saline and high-boron waters. Unfortunately, many of the high-boron waters in the San Joaquin Valley also contain high concentrations of the more common salts. Considering boron independently, and assuming the soil to be initially relatively free from this element, the abundant use of water high in boron to promote a systematic leaching of the root zone is not to be recommended until boron symptoms become pronounced. Such symptoms indicate unfavorable root-zone concentrations. When boron symptoms have become pronounced, the advantage will probably lie on the side of abundant use of water to prevent further increases in the soil and soil-solution concentrations; in other words, the methods used should result in some leaching of the root zone.

WATER SUPPLY OF THE SAN JOAQUIN VALLEY

SOURCES AND GENERAL CHARACTER

Agriculture in the southwestern part of the United States is controlled by the distribution of rainfall, the character of the soils, and the possibility of supplementing precipitation by irrigation. In the San Joaquin Valley the rainfall increases gradually from less than 5 inches in the vicinity of Bakersfield to 16 inches or more in the vicinity of Stockton.

The intensive agricultural development of the valley has followed the utilization of water obtained from wells drilled in the valley floor or in the alluvial fans, and the diversion and use for power and irrigation of water derived from the streams that rise in the mountains to the east. Streams originating in the Sierra Nevada, which rise to great heights above the eastern side of the valley, furnish either directly or indirectly by far the greatest proportion of the water that enters the valley. The remarkably rapid growth of agricultural enterprise in the valley is to be attributed not only to the fertility of the soil and the suitability of climatic conditions for crops but also to the fact that the water furnished by the Sierra Nevada watershed is unusually free from dissolved mineral matter. Those areas along the eastern side of the valley most abundantly supplied with good water are the most intensively cultivated. The supply of water derived directly from rivers of the Sierra or that can be pumped from their alluvial fans is limited, however, and along the eastern side of the valley there has been recently little extension of the irrigated area; rather it has been necessary to deepen existing wells and to install larger pumps in order to maintain the present area.

In addition to the rivers that flow from the high Sierra on the east, there are a number of creeks rising in the Tehachapi and San Emigdio Mountains, which form the southern boundary, and from the coastal

mountains, which form the western boundary of the valley. Principal among these creeks or "washes" are Caliente, Grapevine, San Emigdio, Los Gatos, Cantua, Big Panoche, Little Panoche, Los Banos, San Luis, and Orestimba. All of these are relatively short, and except at flood time their waters are lost in alluvial cones before reaching the axis of the valley. These streams nevertheless are of considerable importance in the present connection, since they are generally considered to have been the source of the underground water supply tapped by wells over a portion of the southern end and the western side of the valley, in which areas irrigation waters contaminated with boron are most frequently found. The water brought in by these creeks likewise carries a much larger amount of dissolved mineral matter than water derived from the high Sierra.

In some sections of the Southwest the contamination of an irrigation water by boron can be traced to some particular spring or group of springs heavily charged with boron but contributing only a minor portion of the stream flow, or to exposed borax or colemanite deposits in a limited portion of a watershed. In the San Joaquin Valley tracing out the sources of boron contamination is generally difficult. In those portions of the valley in which boron occurs in agriculturally significant amounts, the water supplies for the most part are derived from wells, many of which are of great depth and far removed from the streams that now presumably supply or have in the past supplied water to the underground strata. In fact, over a considerable portion of the western side of the valley some of the water now brought to the surface from the deeper wells may be of an age comparable with that of the upper alluvium depositions of the valley itself.

As has been stated by Mendenhall, Dole, and Stabler (*27*):

> The belief that there is little movement in the subsurface waters of the lower San Joaquin is strengthened by a consideration of their chemical characteristics. Some of the ground waters of the upper deltas of the east side are among the purest waters of this type known, while those from the shallow (formerly) flowing wells of the bottom of Tulare Lake and from the deeper wells of the north end of the valley are so heavily charged with mineral matter as not to be potable or suitable for irrigation purposes. Ground waters dissolve the soluble minerals from the rock fragments—the clay, sand or gravel particles with which they are in contact. The amount thus dissolved depends upon the chemical combinations in which the minerals exist, some being much more soluble than others, and upon the length of time during which the waters are in contact with them. In general, the alkalies in the sands and gravels of the east side are in the most resistant form, the silicates of the granitic debris from the Sierra; the alkalies of the sands and gravels of the west side are in less resistant form, the sulphates and carbonates of the Cretaceous and Tertiary shales and sandstones; hence the ground waters of the high parts of the east slopes and the valley, which move with comparative rapidity, are much purer than the waters from similar situations on the west side. Furthermore, the volume of water poured out upon the east-side fans is many times greater than that discharged upon the west side, so that the alkalies dissolved are greatly diluted. But down in the trough of the valley, especially near its north end, the ground waters contain a much larger percentage of salts, even than those of the west side. If there were rapid circulation of ground waters here, this condition should not exist, for the dissolved salts should be gradually carried out. The fact that the waters are highly mineralized is regarded then as additional evidence of sluggish circulation, or perhaps practical stagnation.

GEOGRAPHICAL AND GEOLOGICAL CHARACTERISTICS OF THE VALLEY

The quality of the ground waters as well as that of the streams entering the valley is related to the topography and geology of the valley and its surrounding mountains and foothills. The alluvium

derived from the hard granitic rocks of the Sierra and supplied by water from streams rising in these mountains yields water distinct in composition from that derived from the alluvium of the west side, which has been brought down and deposited in the valley from the more soluble, softer, and often gypsiferous sedimentaries of the Coast Range. The waters derived from the two sides of the valley are in general distinct one from another, but all are highly variable in the concentrations and proportions of their constituents, and both of these waters have contributed to the large body of ground water which extends to great depths beneath the valley. Not only are these underground waters derived from various sources in unknown proportions, but some have been subject to concentration by evaporation and to changes resulting from biological processes. Since the movement of ground water in the valley floor is at most very slow, these waters have long been in contact with the many stratifications of the alluvium of which the valley floor is built, and such contact has served to modify further their quality.

It is because the geographical and geological characteristics of the valley have such a pronounced bearing on the quality of both the surface and ground waters that it has seemed desirable to include in this report a descriptive statement of these features. Mendenhall, Dole, and Stabler (*27, pp. 15–22*) availed themselves of an unpublished manuscript by H. R. Johnson to supply a similar need, and the statement that follows has been taken from their publication almost without change except for the omission of matter of only slightly lesser interest. The contribution by Johnson begins at the third paragraph below:

> The Great Valley of California exhibits little diversity in its physical aspect. Such differences as exist between its north and south ends are climatic, or, if physical, are directly due to climatic differences. Among local physical features based upon climatic differences may be mentioned the Tulare Basin at the south end of the San Joaquin Valley. The basin is due to the aridity of the region and the consequent extensive development of alluvial fans. Two of these, extending from Kings River on the east and Los Gatos Creek on the west side of the valley, have coalesced in a low ridge south of which lie the Tulare Lake and Kern Lake depressions * * *. The southern, more arid third of the depression, extending from Kings River delta to Tehachapi Mountains, has no surface outlet under normal conditions, and the surplus surface waters accumulate in the Tulare Lake depression and Buena Vista reservoir. Originally Kern Lake received a portion of the excess from Kern River, but through the protection afforded by a restraining dike water is kept out of it except when unusual floods break the restraining dam. The original lake bottoms have in part now become valuable wheat lands.
>
> * * * the valley floor has been built up by the alluvial material eroded by the streams from the mountains east and west of the depression and deposited in it. The larger and more active streams build flatter but more extensive alluvial fans—the type that makes up the east-side slopes; the more erratic and torrential streams of smaller volume build the steeper and less extensive fans that constitute the west-side slopes.
>
> In simplest outline the geology of the eastern border of the San Joaquin Valley consists of the "Bedrock series" of granites and metamorphic sedimentary and igneous masses of pre-Cretaceous age, overlain at the north and south ends of the valley in an interrupted band occupying a zone of low relief between the Sierra proper and the valley proper by a series of Tertiary sediments, entirely unaltered and including beds as old as the Eocene, although the great body of the material seems to be Miocene or Pliocene in age. * * *
>
> The geology of the western margin of the valley contrasts in many ways with that of the eastern border. The oldest rocks of the Mount Diablo Range—the easternmost of the coast ranges—comprise a series of altered igneous and sedimentary rocks of Jurassic (?) age known as the Franciscan formation, which

extends along the axis of the range from a point southwest of Coalinga to San Francisco Bay. Overlying them on the valley side, but not continuously, is a series of sandstones, shales, and conglomerates of Cretaceous and earliest Tertiary (Eocene) age. Succeeding these in turn is a variable series, locally of great thickness and usually but not always present in some of its members, representing the middle and upper Tertiary. * * * Toward the top of the series are beds that clearly represent fresh water or subaerial deposition, undoubtedly much like that which is now taking place in Tulare Lake and in the west-side alluvial fans. * * *

The valley as a whole is a great structural trough and appears to have been such a basin since well back in Tertiary time. Since it assumed its general troughlike form, gradual subsidence, perhaps interrupted by periods of uplift, has continued and has been accompanied by deposition alternating at least along what is now its western border with intervals of erosion. This interrupted but on the whole continuous deposition seems to have been marine during the early and middle Tertiary; but during the later Tertiary and Pleistocene, when presumably the valley had been at least roughly outlined by the growth of the Coast Ranges, fresh-water and terrestrial conditions became more and more predominant, until the relations of land and sea, of rivers and lakes, of coast line and interior, of mountain and valley, as they now exist, were gradually evolved. As these conditions developed, the ancestors of the present rivers probably brought to the salt and fresh water bodies that occupied the present site of the valley and its borders, or, in the latest phases of the development, to the land surface itself, the clays, sands, gravels, and alluvium that subsequently consolidated into the shales, sandstones, and conglomerates of the late Tertiary and Pleistocene series, just as the present rivers are supplying the alluvium that is even now accumulating over the valley floor.

The very latest of these accumulations are the sand and silt and gravel beds penetrated by the driller in his explorations for water throughout the valley. They are like the early folded sandstones, shales, and conglomerates exposed along the flanks of the valley, except that they are generally finer, and are not yet consolidated or disturbed. The greater part, perhaps all of them, accumulated as stream wash on the valley surface or in interior lakes like the former Tulare Lake, but a proportion of the older sediment that is greater as we delve farther back into the geologic past accumulated in the sea or in salt bays having free connection with the sea. It is these very latest geologic deposits, saturated below the ground-water level by the fresh water supplied chiefly by the Sierran streams, that constitute the reservoirs drawn upon by the wells, whether flowing or pumped, throughout the valley.

The chemical composition of the ground waters, as well as their occurrence and accessibility, is related to the geology. Where the valley alluvium is derived from the Cretaceous and Tertiary beds of the coast ranges, rich in gypsum and other readily soluble minerals, the ground waters [generally] contain large quantities of these salts. Where, on the other hand, the alluvium is derived from the granites and metamorphic rocks of the Sierra, whose potassium, sodium, and calcium compounds are in the form of difficultly soluble silicates, the ground waters under ordinary conditions contain very little of these salts.

Obviously if the sands and gravels through which the ground waters percolate were deposited under such conditions that salts were deposited with them, as in the salt water of the sea or of bays like San Francisco Bay, or in interior lakes that are saline through evaporation, as is true of Tulare Lake, then the ground waters themselves become saline, although when they leave the mountains as surface waters, before their absorption by the alluvial fans, they may be as pure natural waters as are known in the world.

The lowland through the heart of California known as the Great Valley, whose origin as a depression appears to date well back into Tertiary time, owes its actual surface to more recent action and to more obvious agents. That surface is, in brief, a combination of the surfaces of a great number of alluvial fans, originating at the mouths of the canyons through which the tributary streams discharge from the mountains into the valley.

* * *

The essential fact as to the present valley surface is that it is a direct result of stream action. It has everywhere been built up by deposition from the streams or from the fluctuating lakes that are themselves dependent upon the streams; and it is formed of materials brought by the streams from the mountainous portions of their drainage basins where they are eroding instead of depositing. Throughout the south end of the valley its surface is a combination of alluvial fan

surfaces; at the north end of the valley these fans, less strikingly and typically developed because of the greater precipitation there, still predominate along the valley borders, while the center of the valley is a flood plain of the usual type.

* * *

The west-side streams, draining mountains practically free from granitic and similar rocks but with soft serpentines, shales, and sandstones, deposit fragments of those rocks in their alluvial fans, and the result is a soil type entirely different from that of the east side and south end of the valley. These shale, clay, serpentine, and sandstone fragments disintegrate much more quickly than the granitic sands that contain large proportions of such resistant minerals as quartz and feldspar, and the result is the mellow, loamy soil with its fragments of siliceous shale that makes much of the west slope of the valley and is so productive whenever water can be applied to it.

FIRST OBSERVATIONS OF BORON INJURY IN THE VALLEY

As early as 1922 W. S. Ballard, of the Bureau of Plant Industry, noted a similarity between the symptoms shown by certain plants in the vicinity of the Rock Pile School, southeast of Bakersfield, and the symptoms that had been illustrated as resulting from the application of borax with fertilizers in Eastern States. Ballard encountered difficulties with analytical methods and with experimental plants and made no published comment on his observations. He called the conditions in the Rock Pile area to the attention of C. S. Scofield, in charge of Western Irrigation Agriculture, Bureau of Plant Industry, in 1929. About the same time A. R. C. Haas, of the California Agricultural Experiment Station, called attention to boron symptoms that he had observed in citrus near the Weed Patch store, also southeast of Bakersfield. Boron determinations on samples collected by Scofield established the cause of the crop injury in the Rock Pile area and at Weed Patch. A water sample sent in from Lemoore was likewise found to contain an injurious concentration of boron.

Observations of the symptoms exhibited by plants and the analyses of a few scattered water samples collected by the writer in the valley in June of the same year resulted in the conclusion that injurious concentrations of boron were possibly common to many of the well waters along the west side of the valley. No evidence of boron injury was observed in plantings east of the valley axis north of Kern County. These observations pointed to the desirability of the investigations in the San Joaquin Valley which are reported in this bulletin.

QUALITY OF IRRIGATION WATER

INJURIOUS CONCENTRATIONS OF BORON

Before attempting to attach significance to particular concentration ranges of the boron found in irrigation water it is desirable to review a number of the factors that are known or believed to influence the evidence of injury and the accumulation of boron in soils as produced by boron-contaminated water.

The tolerance of the crop or crops grown is in the front rank of importance; alfalfa and sugar beets will do well with boron concentrations in the soil solutions to which cotton and cereals show depressed yields and at which the profitable culture of grapes and many of the deciduous fruits would be out of the question.

A heavy soil initially low in boron will usually remain productive for a longer time than a light soil when water high in boron is used, but after injurious concentrations have been built up in soils the light

soil will respond quicker to the substitution of a good water. The existence of marked differences in the boron-fixing powers of both light and heavy soils is appreciated, but little is known of the chemical character of the reactive constituents.

The initial boron content of the soil is of obvious significance, since upon this there is dependent the delay in the onset of adverse symptoms when water high in boron is used.

Boron injury is accentuated by climatic conditions causing high transpiration rates.

The annual quantity of water applied is of significance. Boron will be added to the soil more rapidly when water is supplied in quantities required for such crops as alfalfa and cotton than when lesser quantities are used, as for cereals.

The amount of rainfall is of special significance, since this reduces the amount required by irrigation. Rain water, being free of boron, constitutes an effective agent in leaching boron from the root zone. Highly undesirable boron concentrations in irrigation water in arid localities may have little significance in regions of heavier rainfall.

The effects of boron are similar to those of other toxic elements on plants, in that above certain minima a decrease in plant growth results from any increase in the concentration of the toxic substance. The point of diminished growth selected as critical from an agricultural viewpoint must be chosen somewhat arbitrarily and is certainly contingent not only on plant growth but on economic factors such as the cost of crop production and market values. It is obvious that neither the concentration at which injury first appears nor the concentration that kills the plant is as useful a criterion as some intermediate point of diminished yield. The conditions in the soil solution resulting from the use of a given water are in general not stationary but vary with time as the toxic substances are concentrated in the soil by transpiration and evaporation, become insoluble by soil reactions, or are leached away by water penetrating beyond the root zone.

With the foregoing considerations in mind it should be apparent that any statement of what constitutes dangerous concentration of boron in an irrigation water must be phrased only in the most general terms. This is particularly true in an area as extensive as the San Joaquin Valley with its diversity in quality of irrigation waters, soil types, crops, and climatic conditions.

In terms of suitability of water for those plants listed as being sensitive to boron, a most conservative statement for the southern portion of San Joaquin Valley would be that above a concentration of 0.3 p.p.m. the less boron in an irrigation water the better. In Ventura County, to the south, where rainfall is 10 inches or more and where both the temperature and the humidity are affected by the Pacific Ocean, a water containing much more than 0.5 p.p.m. of boron is considered as being of doubtful quality for the irrigation of lemons and walnuts. In the latter area higher concentrations have been used without appreciable injury under some conditions, but in at least one instance the prolonged use of a water with only slightly more than 0.4 p.p.m. of boron has injured the foliage of lemon trees. In the more arid portions of the San Joaquin Valley, where the annual rainfall is about 5 inches and the transpiration rate is high, injury may result to plants of the sensitive group with water containing 0.5 p.p.m. of boron, or, under favorable conditions, the more tolerant of the sensitive

crops may make a fair or even profitable growth for a period of years with water containing as much as 1 p.p.m. of boron.

In the arid parts of the valley the growth of plants of the semitolerant group may be adversely affected by as little as 0.5 p.p.m. of boron in irrigation water in localities where appreciable boron occurs as a native constituent of the soil or where conditions are such that excessive concentration takes place in the root zone. Under more favorable conditions and with soils that remain open to leaching, reasonably satisfactory growth can be expected from semitolerant plants with water containing from 1 up to 2 p.p.m. of boron. When the boron concentrations exceed 1.5 or 2 p.p.m. the best results can ordinarily be expected only with plants of the tolerant group.

The effects of boron are less severe in those parts of the valley with higher rainfall. Where the water is supplied nearly equally by rain and irrigation only about half the injury experienced in the more arid portions of the valley is found.

In all considerations of toxicity the standard of injury or of reduced yields is of great importance. The family of a dry-land farmer southeast of Bakersfield has recurrently endeavored to grow a little garden as well as ornamental plants and dooryard trees with well water containing 7 p.p.m. of boron. It is true that many plants have been found entirely unsuited and that the condition of the perennial plants grown is far from satisfactory, and yet there is no question that the efforts to maintain a little home garden and a few trees are worth while. A water containing 5 p.p.m. of boron in Lost Hills was used for a short time but was found to be unsatisfactory even for a lawn, and cottonwood trees and other plants at this place bore marked evidence of injury. Tamarisk trees grow fairly well with water containing 15 p.p.m. of boron, and a number of other plants have been grown with such water when placed in pots or boxes to permit of the drainage necessary for copious irrigation.

SIGNIFICANCE OF OTHER CONSTITUENTS OF IRRIGATION WATERS

It has been found essential in these investigations to determine the concentrations of constituents other than boron in the irrigation waters examined. Though no general relationship has been found to exist between the concentration of boron and the concentration of any other constituent, there is a marked tendency nevertheless toward higher boron concentrations in the more highly mineralized waters. In some of the San Joaquin Valley waters boron is the only dangerous constituent, but more commonly when boron is high other ions are also high, and there are many saline waters that contain very little boron.

The injurious effect of boron is modified to some extent by other constituents of irrigation waters; and since the ill effects of the various constituents are in a measure interrelated and additive, it is clear that the significance of one characteristic of the salt complex cannot be properly evaluated independently of a knowledge of the others.

In the previous section a number of factors were enumerated which modify the rate at which boron accumulates in soil and influence the effects that follow the use of boron-contaminated water. A variety of factors likewise influence the effect of higher concentrations of the other toxic ions, and for that reason it is not possible to indicate critical concentrations of these ions in other than general terms.

The ill effects that follow the accumulation of toxic substances in the soil are due less commonly to direct injury to plant roots than to effects upon foliar and other tissue after these substances have been absorbed and concentrated within the plant. Climatic factors and the balance of ions in the soil solution may affect absorption rates, but the concentration of salt constituents presented to roots by the soil solution stands out as a predominating factor in the determination of the concentration built up within the plant tissue and the injury that results. The high osmotic force of the soil solution when it has become concentrated has sometimes been pointed to as a deterrent to the free absorption of water from the soil by the plant; but in other than rather unusual cases, as when the soil solution concentration may have been suddenly increased by the application of water more saline than customarily used, or by the washing of surface salt into the root zone, this relationship is of secondary importance. It has been shown elsewhere by the writer (*12*) that plants maintain osmotic concentrations in their tissues which exceed those of the soil, the concentration within the plant being higher when the salinity of the soil is higher. Within the limits of tolerance, a tendency toward a uniform difference between the plant and soil concentrations is indicated in soils of varied salinity, but this gradient would be expected to vary for each variety and habitat.

It is well known that plants differ to marked degrees in their tolerance of the different salt constituents, but information comparable to that presented in table 1 for boron is not available. Hilgard (*18*) has published a table of plant tolerances compiled by R. H. Loughridge which sets forth the highest concentrations of sulphate, carbonate, chloride, and "total alkalis" found in soils supporting uninjured plants. The work upon which this table was based was done long ago, and it is still recognized as a valuable and comprehensive source of information, but in the terms of present-day knowledge its limitations are manifest. The plant habitats investigated were undoubtedly limited in number and variety, and conclusions as to whether plants were or were not affected would seem now to be almost impossible except by comparison with similar plants grown on nonsaline or nonalkaline soils. The growth of many plants may be materially reduced by sulphate and chloride ions without the development of symptoms indicating that fact. Hilgard's table reports the tolerances of different plants to each of three, independently considered, soil ingredients, but he recognized that the proportions of these ingredients found in nature were extremely variable. It is likewise to be recognized that the salt concentrations in the different horizons of the root zone may vary widely. A question therefore arises as to which soil layer was or is to be taken as a criterion of tolerance, or what significance is to be attached to composite samples from several different horizons. In the table cited account was taken only of the acid radicals, but it is now known that different proportions and concentrations of the bases, calcium, magnesium, potassium, and sodium, greatly affect plant growth and soil characteristics; these bases, collectively, are always present in concentrations equal to those of the acid radicals. The point here made is that we do not know for any one set of conditions the comparative tolerances of the various agricultural plants to the common ions nor the extent to which plant growth is depressed by the various combinations and concentrations.

The difficulties encountered in attempting to assign critical or toxic limits for these irrigation-water constituents, however, do not end at this point. It is the concentration of salt in the soil solution, and not the concentration in the irrigation water, which determines plant reactions. The concentration of the different salt constituents in the soil solution may exceed by many times that in the water applied. Cultural practices as well as climatic factors and the kind of crops grown are all of importance, and there is to be stressed also the permeability of the soil as it affects the removal of salts from the root zone by leaching and the abundance with which water is used to accomplish this. Waters sufficiently high in toxic constituents to be directly injurious to plants are seldom used for irrigation. Transpiration by the plant and evaporation from the soil both serve to increase the concentration of the soil solution above the concentration of the water applied. On the other hand, water, either irrigation or rain, when in sufficient abundance, displaces in part the soil solution, which, being removed downward, carries salt beyond the root zone. In addition to the salt removal by leaching, small quantities are absorbed by plants, the quantities thus removed being dependent upon the type of plant, the portions of the plant removed from the land, and the concentration of the different constituents of the soil solution presented to the roots.

Plants may absorb the individual constituents of the soil solution either in a greater or lesser proportion than they absorb water, but under the usual conditions in irrigated regions the soil solution is left more concentrated in chlorides and sulphates as a result of plant transpiration. It is not to be assumed that the absorption of salt constituents is determined wholly by plant needs. A plant may absorb such salt constituents as chlorides and sulphates to an extent that certain of its growth processes are impaired as a result of chemical effects. Yet it is obvious that if the growth processes are to be carried on the plant must absorb water from the soil solution, and insofar as this absorption depends upon osmosis it is obvious that the osmotic concentration of the plant sap must be higher than that of the soil solution.

In sand cultures of mixed deciduous fruits and grapes maintained with a nutrient solution containing 1 p.p.m. of boron, the solution removed by the plants over a 21-day period was only 14 percent as concentrated in boron as that presented to the roots. In cultures maintained with a 6 p.p.m. boron nutrient solution the absorbed solution was 16 percent as concentrated as that presented. These same solutions each contained initially 3 millimoles per liter of magnesium sulphate, and a known amount was added with the water used to replace a part of the transpiration loss. In the low-boron and high-boron treatments cited, the solutions taken up by the plants were respectively 5 and 7 percent as concentrated in sulphates as were the solutions presented. In a culture with 9 p.p.m. of boron in which the grape was the predominating plant, the solution removed was 32 percent as concentrated in boron and 21 percent as concentrated in sulphate as that presented to the roots. With other solutions and other plants different percentages have been obtained, but these given are illustrative. The concentrations of the solutions removed by the plants were estimated from the known initial and end concentrations of the culture solutions and the quantity of water transpired.

The preceding discussion has been presented for the primary purpose of showing why it is not possible to set definite limits for the critical concentration of any of the common constituents of irrigation waters. Not only do the tolerances of different plants vary, but no fixed relationship can exist between irrigation-water concentrations and soil-solution concentrations, and it is the latter rather than the former which determines plant behavior. Notwithstanding these limitations, standards of reference are desirable, and when properly interpreted they are of value.

Chlorides in a water supply ordinarily cannot be expected to produce injurious effects of material consequence below a concentration of 4 or 5 milligram equivalents per liter, whereas some injury is generally certain above 8 or 10 m.e. Toxic effects from sulphates cannot ordinarily be expected from water containing less than 7 or 8 m.e., but they are highly probable above 20 m.e. The effects of chlorides and sulphates between these limits are relative to conditions and crops, and the limits are of only moderate significance, since outstanding exceptions might be noted. In view of the uncertainties occasioned by varied conditions, it is preferable to think of the quality of waters with respect to chlorides as being better as the chloride concentrations drop below 7 m.e. and poorer as they exceed it. For sulphates, 12 m.e. provides an equally suitable base.

The concentration of bicarbonate (HCO_3) in irrigation water is of secondary importance, and for practical purposes it may ordinarily be omitted from quality-of-water considerations. At one time bicarbonate was supposed to be as toxic as chloride or sulphate, but that view is not now generally held.

It is customary to regard the basic constituents of irrigation waters, i.e., the calcium, magnesium, potassium, and sodium, first in the light of their potential effects upon the physical character of soils. Different proportions and concentrations of these ions in the soil solution have effects also upon plant growth, but the information now available does not lend itself to field interpretation in terms of the quality of irrigation water, and for that reason the subject cannot be satisfactorily dealt with.

The ratio of alkali bases, i.e., sodium and potassium, to the alkaline earth bases, calcium and magnesium, is of particular significance, since upon this ratio the maintenance of permeability of soils to irrigation water is many times dependent. An impermeable soil not only provides an unsatisfactory seed bed and prevents good aeration but it takes water slowly and does not leach freely. An irrigation water of given salinity used in sufficient abundance may be entirely satisfactory on a permeable soil and yet render unproductive other soils that may not be adequately leached.

When sodium constitutes a large proportion of the bases of an irrigation water, similar relationships must ultimately exist in the soil (*32*). The rapidity with which such changes are brought about is contingent not only upon the proportion of sodium in the water and its concentration but likewise upon the proportions and amounts of replaceable calcium and magnesium and sodium in the exchange complex of the soil. In one section of the area here dealt with, where sodium is the predominant base in the irrigation waters, farmers recognize that such profit as is to be obtained from their land must be obtained during the first few years of irrigation. Yields of 30 sacks of

barley the first year are followed by yields of 12 to 15 sacks the third year, and it is then necessary to let the land lie fallow for a year before it can be brought into sufficiently good tilth for a seed bed for a fourth crop.

Just as it was indicated as hazardous to set up well-defined limits of tolerance for salts in irrigation waters, so it is not yet possible to assign definite limits for sodium as a percentage of total bases in irrigation waters.

For each of the water analyses to be reported the alkali bases (sodium and potassium) are presented both in terms of concentration and also as percentages of total bases. Inasmuch as the analyses are set forth in milligram equivalents, it is largely immaterial whether these percentages are read as sodium as percentage of total bases or sodium salts as percentage of total salts. The inaccuracy occasioned by considering the total alkali bases as being sodium is not of great consequence, because the effect of potassium, which is rarely present in high concentrations, is regarded as being like that of sodium. Calcium and magnesium may be considered as nearly alike in their effects upon the soil. Waters carrying sodium to the extent of 65 percent of the total bases are looked upon as being of doubtful quality, waters with less than 50 percent as being wholly satisfactory in this regard, and those with more than 65 percent of sodium as presenting a progressively greater hazard as the percentage increases. But with this interpretation it must be recognized that water very low in total salinity, even though sodium predominated, might be used for many years on a soil high in calcium carbonate or in adsorbed calcium and magnesium.

Gypsum, sulphur, or the salts of iron and aluminum (*24*) are sometimes used successfully for the improvement of soil structure and for promoting reclamation where impermeability is serious. The gypsum equivalent of 1 m.e. of calcium per liter is 234 pounds per acre-foot of water. If water with 69.2 percent of sodium has, for example, 4 m.e. of calcium and magnesium combined and 9 m.e. of alkali bases, the difference in the sums of the alkali bases and the alkaline earth bases is 5 m.e. per liter. To give equal proportions of alkali bases and alkaline earth bases in such water it would be necessary to add to each acre-foot of water 1,170 (5×234) pounds of gypsum. To reduce the alkali-base concentration to 60 percent of total bases 468 (2×234) pounds of gypsum would be required. If the alkaline earth bases exceed the alkali bases, the gypsum equivalent of the excess calcium and magnesium can be computed in a similar manner.

Apprehension exists in the minds of a few growers and agricultural advisers that gypsum taken from deposits in regions where the waters have been found to carry substantial concentrations of boron might likewise be contaminated. Boron determinations have been made on 8 samples of gypsum, 5 of which were collected near Panoche Creek southwest of Mendota, 2 from Lost Hills, and 1 from Imperial Valley. One of these samples showed no boron, 2 had 22 p.p.m., and the average of the 8 was 8.4 p.p.m. The results obtained from the 8 samples do not constitute evidence that boron compounds are never deposited with gypsum, but indicate that there is no particular reason for suspecting such contamination. Ten tons of gypsum con-

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taining 22 p.p.m. of boron would add to the soil but 0.4 pound of boron, or approximately the amount added by 1 acre-foot of water containing 0.16 p.p.m. of boron.

The specific electrical conductance, $K \times 10^5$ at 25° C., as given for each of the water analyses, provides an index of the total salinity of the water comparable to that provided by total solids, but neither measurement indicates the nature of the ions present. Waters with conductances below 75 will not ordinarily contain a sufficient concentration of any of the common ions to produce injurious effects, but between conductances of 75 and 150 uncertainty must exist in the absence of chemical analysis. An electrical conductance above 200 is definitely significant of a poor water, although sulphate waters high in calcium and magnesium with conductances above 300 have been used profitably for long periods.

INTERPRETATION OF ANALYSES OF IRRIGATION WATERS

The common mineral constituents of natural waters may be divided into two groups, namely, those existing in ionic forms with definite chemical affinities for other constituents, and those held in suspension as molecular aggregates possibly in the colloidal state. The latter group probably includes a portion of the silica, and oxides of iron and aluminum. Natural waters contain in addition dissolved gases, chiefly oxygen, nitrogen, carbon dioxide, and not infrequently hydrogen sulphide or sometimes hydrocarbons. The concentrations of these colloidal and gaseous constituents have been determined in this work in only a few instances, and these determinations are not given in the analyses that follow in this bulletin. The constituents of the other group, the ionic group, are of two kinds, (1) the positively charged bases, principally calcium, magnesium, sodium, and potassium, and (2) the negatively charged acid radicals, principally carbonate, bicarbonate, chloride, sulphate, and nitrate. The several constituents of each kind have different but definite capacities for reacting with or holding in solution the constituents of the other kind. The two kinds of constituents in a water are always in chemical equilibrium; that is, the sum of the milligram equivalents (or reacting values) of the positive radicals is always equal to the sum of the milligram equivalents of the negative radicals.

An analysis that includes only the ions mentioned is never complete, for in practically all natural waters other chemical substances are present. These other elements, or radicals, which may be of widely varied character, are usually present in low concentrations, and their identification and accurate estimation is often difficult or may require special apparatus, and they are not determined in the ordinary chemical analysis. Boron belongs among these secondary substances. Formerly it was rarely included in an analysis of agricultural water or soil, since its agricultural significance was not appreciated. Only recently have accurate analytical methods for the estimation of boron in very low concentrations been developed.

ANALYSES OF WATERS OF THE SAN JOAQUIN VALLEY

In the following pages are reported the analyses of approximately 450 water samples from streams and wells of the San Joaquin Valley. The samples were collected and analyzed primarily to determine to what extent boron occurs as a natural constituent of the surface and

underground waters in the area. The waters examined were for the most part irrigation waters. Some other waters not then used for irrigation but which had been used and abandoned or which might at some time be developed for agricultural use were also collected, and some additional samples were examined, particularly those of foothill streams, wells, or springs, because of the implications afforded with respect to the quality and source of valley waters.

Within the area drained by the San Joaquin River and its tributaries there are 2,405,308 acres of irrigated land (approximately one-half of the total irrigated acreage of California) and an additional 1,157,322 acres which are reported as of 1929 as capable of being supplied with water by existing irrigation enterprises (*38*). Extensive areas underlain with water-bearing sands have been developed only in part.

Boron occurs in higher concentrations in the waters of some regions than in others. It was anticipated that the data resulting from the survey would serve a general purpose by indicating in which portions of the valley boron should receive particular attention in extending agricultural developments and to what extent agricultural problems in developed portions of the valley were attributable to high boron concentrations. The analyses here presented are limited in number and are expected therefore to serve only as guides in these matters, and this function was in view when the work was undertaken. Insofar as the results may direct attention to the importance of boron as a potentially toxic constituent of irrigation waters and so stress the desirability of examining waters for this constituent, the work will have accomplished an additional purpose. Such constituents as chlorides and sulphates have long received serious consideration in the utilization of irrigation waters, but only recently has attention been directed toward the frequent occurrence of boron in irrigation waters and the highly toxic effects upon plants that result from relatively small concentrations.

Boron has been found to be present in each of some 4,000 surface and underground waters so far examined by the Division of Western Irrigation Agriculture in the western portion of the United States. In some of these waters its concentration has been sufficiently high to inhibit the growth of irrigated plants, and in others so low that its presence was demonstrated only by special methods.

The analyses of the San Joaquin Valley waters were not limited to boron determinations but included also determinations of bicarbonate, chloride, sulphate, calcium, magnesium, and alkali bases.

Following the analytical tables and sample descriptions the general characteristics of the waters of different portions of the valley are briefly discussed. For each of the smaller geographical units into which the valley was subdivided for purposes of presentation a more detailed description of the water supplies has been undertaken.

In the preceding pages it has been emphasized that attention should be given to the percentage of sodium in irrigation waters. In the last column of each table of analyses the sodium percentage in each of the samples has been calculated, and the significance of these figures cannot be overemphasized. Their calculation and inclusion in reports of water analyses represent a new departure which it is believed should be generally adopted. The writer has found the concept to be one of great importance in the area studied.

COLLECTION OF SAMPLES

Not all of the water supplies sampled in the area covered by this report have contained appreciable concentrations of boron, and relatively few samples have been collected east of the trough of the valley. The east side of the valley is the most highly developed and is of the greatest agricultural importance for the reason that the quantity of water derived from the Sierra greatly exceeds that derived from the eastern watershed of the coastal mountains. The west side of the valley has received the greater attention in this work, since both preliminary and later observations and collections indicated that boron occurred in appreciable amounts in many of the west-side wells, whereas except for areas in the south end of the valley, little or no evidence of boron injury resulting from the use of water from streams or wells east of the valley trough has been found.

In undertaking the work a general rather than a detailed survey was contemplated, and an effort was made to collect representative samples over the entire west-side area. Nevertheless, more samples were collected in areas where boron contamination was thought to be local and where marked differences were indicated in the quality of the water of neighboring wells or in the different water-bearing strata. More numerous samples were sometimes collected at the solicitation and with the cooperation of property owners when the problem of water quality was thought to be of immediate economic concern.

It has been possible for the writer to collect personally the greater number of the samples, but when any were collected by others the name of the collector is given. For the most part and insofar as practicable, sample collections were confined to the summer or early fall, for it is during the latter part of the season that the effect of boron in irrigation water upon crops is most clearly indicated. Detailed notes on plant reactions for comparison with the subsequent analytical results were regularly taken. The interpretations of the significance of boron concentrations in irrigation water in the different parts of the valley (p. 27) were based upon these observations and upon the severity of symptoms and associated reduction in growth of plants grown experimentally at the Rubidoux Laboratory.

EXPRESSION OF ANALYTICAL RESULTS

At one time nearly all water analyses in other than purely chemical papers were reported as grains per gallon. Parts per million later came to be the more popular unit and is still ordinarily used. In this work it has been elected that the analyses should be reported in milligram equivalents per liter, the reason being that concentrations so expressed more clearly portray the chemical composition of a water, and the analyses so reported most readily lend themselves to agricultural interpretation.

Parts per million is a gravimetric expression which sets forth the weight of a given constituent in a given weight of water, whereas by milligram equivalents a statement is made of the number of ions of each constituent present. The essential difference between the two forms of expression may be simply illustrated by assuming an aquarium containing various kinds of fish. If it is stated that there are so many pounds of each kind of fish in a million pounds of water, the analysis of the population has been expressed in parts per million.

By stating that there are so many of each kind of fish in a given volume of the aquarium, a form of census is adopted which is comparable to that used when the concentrations of the various ions in a water are expressed in milligram equivalents. In other words, the one form of expression concerns itself with the mass of the different constituents and the other with the number of chemical units.

In chemical terms a solution containing 1 milligram equivalent per liter of any ion is one one-thousandth normal with respect to that ion. If water is added to 1 gram of sodium chloride (common salt) to make a liter of solution, that solution contains 393.4 p.p.m. of sodium and 606.6 p.p.m. of chloride. This same solution contains 17.1 m.e. per liter each of sodium and chloride.

If gypsum is added to a water, the numbers of calcium and sulphate ions are increased equally, but gravimetrically the concentrations are increased in the proportion of 20 p.p.m. of calcium and 48 p.p.m. of sulphate. Likewise in base exchange considerations, if sodium of a water exchanges places with calcium of the soil it does so equivalent for equivalent, but gravimetrically expressed in the proportion of 23 p.p.m. of sodium for 20 p.p.m. of calcium.

Boron is expressed in parts per million because its concentration is normally too low to require consideration in the balancing of ions, and the nature of the ion or ions in which it occurs is not known; also, if boron concentrations were expressed in milligram equivalents the concentrations frequently found would lie in the third decimal place, which would make verbal discussion awkward.

The concentration of any ion expressed in milligram equivalents per liter may be converted to parts per million by multiplying by the factor that results when the atomic weight of the ion is divided by its valence. The factors for a number of the common ions are as follows:

Ion	*To convert milligram equivalents to parts per million multiply by—*
Bicarbonate (HCO_3)	61.0
Chloride (Cl)	35.5
Sulphate (SO_4)	48.0
Nitrate (NO_3)	62.0
Calcium (Ca)	20.0
Magnesium (Mg)	12.2
Alkali bases (by difference, as sodium)	23.0
Total hardness (as $CaCO_3$), take sum of calcium and magnesium and multiply by	50.0

To convert parts per million to grains per gallon, multiply by 0.0584; or to convert grains per gallon to parts per million, multiply by 17.12. To convert parts per million to pounds per acre-foot of water, multiply by 2.72.

The specific electrical conductance (K) is the reciprocal of the resistance in ohms offered by a water to the passage of electricity between two electrodes of standard dimensions and spacing. For convenience of expression the decimal is moved five places to the right; thus, $K \times 10^5 = 129$ is the same as $K = 0.00129$. Electrical conductivity, being a function of the number and nature of ions in solution, is more directly related to the sum of ions expressed in milligram equivalents than are values for total solids which represent the weight of all ions in a given volume of solution. The electrical conductance of a solution increases with temperature, and for that reason the temperature at which a conductance measurement is made

must be stated. In this work all conductance determinations have been reported as at 25° C. The total salt content in parts per million of some ordinary waters can be estimated approximately from conductance values by multiplying the conductance by 6 if it is less than 100 or if chlorides predominate, and by 7 if the conductance is over 100 or if sulphates predominate. A conductance of 100 is roughly equivalent to 1 ton of salt per acre-foot of water.

The boron concentration is expressed as parts per million of elemental boron in the solution. Two places to the right of the decimal are reported, but full confidence in the second of these is not implied. The titrating solution used in the Wilcox modification (*41*) of the Chapin method was of such concentration that 0.05 milliliter of it was equal to 0.01 p.p.m. of boron in aliquots of the size used. While the error of such a burette reading is not great, there are other sources of error in the process of analysis.

Carbonate and bicarbonates (CO_3 and HCO_3) are reported together in the analyses because very few water samples contain appreciable amounts of normal carbonate and the equilibrium between carbonates and bicarbonates is influenced both by temperature and aeration either before or after sampling.

The alkali bases are assumed to include sodium and potassium, but neither of these elements has been directly determined in the greater number of analyses. The values reported in the tables were obtained by the customary procedure of adding together the milligram equivalents of bicarbonate, chloride, and sulphate and from that sum subtracting the sum of calcium and magnesium. In nearly all waters sodium greatly exceeds potassium, and for all practical purposes the quantity of alkali bases reported can be interpreted as sodium.

The percentage of alkali bases (sodium principally) of the total of all bases (calcium, magnesium, sodium, potassium) has been calculated for each analysis and is designated in the final column of the tables as "percent sodium".

METHODS OF ANALYSIS

The chemical analyses herein reported were made by L. V. Wilcox, Vladimir Sokoloff, and Francis C. Scofield, all of the Division of Western Irrigation Agriculture of the Bureau of Plant Industry. The procedures in brief were as follows:

Conductance.—The specific electrical conductances were determined at 25° ± 0.1° C. by the conventional procedure and with the usual apparatus, which in this case consisted of a Wheatstone bridge of the slide wire type, batteries, 1,000-cycle microphone hummer, and suitable electrode vessels either of the pipette or the immersion type. The pipette electrode had a cell factor of about 0.30 and the immersion type about 1.30. The electrode vessel was standardized each time of use and always rinsed with a duplicate sample at the same temperature before each reading.

Boron.—Up to and including sample no. 4500, the boron determinations were made by the Wilcox modification (*41*) of the Chapin method. Subsequent to that number the determinations were made by the electrometric titration method (*42*).

Carbonate and bicarbonate.—The carbonate and bicarbonate ions were titrated with 0.05 normal sulphuric acid, phenolphthalein indicator being used for the carbonate ion and methyl orange indicator for the bicarbonate ion (*2, p. 93*). Aliquots of 50 milliliter were titrated with 0.05 normal acid, so that a burette reading of 0.05 corresponded to 0.05 milligram equivalents.

Chloride.—To the neutral solution resulting from the carbonate-bicarbonate titration, 1 cc of potassium chromate indicator was added. Chloride was then titrated with 0.05 normal silver nitrate solution. This is the official method.

Sulphate.—Sulphate was determined gravimetrically as barium sulphate from a 200-cc aliquot. The official method was followed except that silica was not removed prior to the precipitation of the barium sulphate. The relatively small amount of silica does not interfere so long as the volume is not evaporated below 75 to 100 ml. The calcium sulphate, anhydrous, equivalent of the sulphate ion may be computed in parts per million by multiplying the sulphate concentration by 68.

Calcium.—The calcium ion in all samples bearing numbers above 767 was precipitated as calcium oxalate and titrated with permanganate (*5*). Calcium and magnesium, in the few samples carrying serial numbers of 767 or below, were separated and determined by the Winkler modification of the Clark soap method, as reported by Grittner (*15, p. 847*).

Magnesium.—Through sample no. 2300, magnesium was determined by the soap method (see calcium). Subsequent to sample 2300, magnesium was determined by precipitation as magnesium ammonium phosphate, which was ignited and weighed as the pyrophosphate.

Alkali bases.—The amount of alkali bases, sodium and potassium, was estimated in nearly all of the analyses without direct determination by subtracting the sum of the calcium and magnesium ions from the sum of the acid radicals.

Sodium percentage.—The expression "percent sodium" takes into account the ratio of the sodium content to the sum of the calcium, magnesium, and the alkali bases, the concentrations of all three constituents being expressed in terms of milligram equivalents. In other words, the percentage of sodium is obtained by dividing the sum of the milligram equivalents of calcium, magnesium, and alkali bases (*AB*) into the figure for the alkali bases and pointing off two places to the left, according to the following formula:

$$\text{"Percent sodium"} = \frac{AB \times 100}{\text{Ca} + \text{Mg} + AB}$$

METHOD OF PRESENTING ANALYTICAL DATA

For the presentation of the analytical data of this report and the orderly arrangement of office records the area here dealt with has been subdivided into quadrangles of uniform size. Each of these quadrangles embraces an area 18 miles wide in an east and west direction by 24 miles long from north to south and includes therefore 12 townships. Except for portions of the valley floor adjacent to the Sierra Nevada, all of the San Joaquin Valley is included in one or another of 35 of these quadrangles. A sketch map of each quadrangle has been prepared. Where a representative number of samples were collected in any one, the map has been reproduced facing or adjacent to the corresponding table of analyses. The locations of the sources of the samples are shown on the maps by numerals which appear also in the first column in the tables of analyses. Samples representing surface waters are identified by a letter S placed adjacent to the location number on the quadrangle maps and following the location number in the tables of analyses. Following each table of analyses there is given a brief description of each of the samples.

A key map (fig. 2) is provided, which designates by township and range as well as by number the respective locations in the valley of the area embraced in each quadrangle. Townships and ranges of quadrangles 1 to 32, inclusive, are referenced to the Mount Diablo meridian and base line, and those of quadrangles 33 to 35 to the San Bernardino meridian and base line.

The quadrangle maps show with a fair degree of accuracy the locations of the important towns and streams and a little of the locations of lines of foothills; they are intended, however, to be

diagrammatic rather than precise, and all are drawn on a common base sketch of townships and sections. A part of the area is unsurveyed, and where surveyed the sections and townships are frequently not of regular shape. Certain samples were taken in unsurveyed

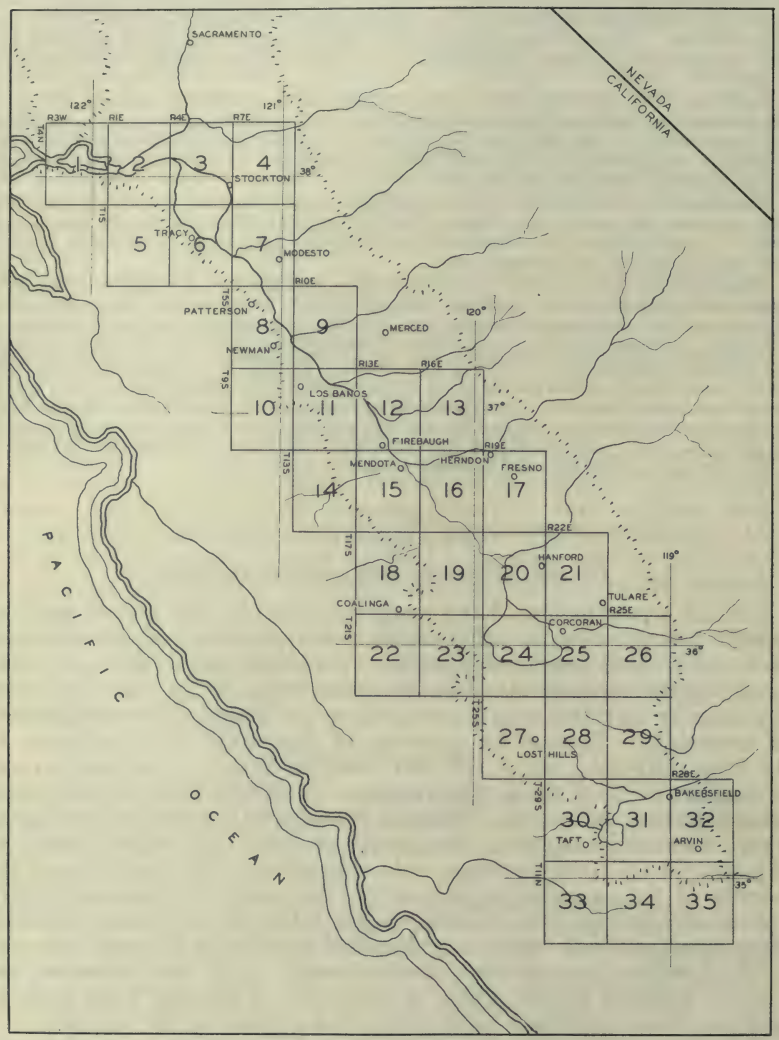

FIGURE 2.—Key map showing locations of areas embraced in the numbered quadrangle maps and the corresponding tables.

territory, and these are located on the maps in terms of section, township, and range by projecting township and section lines into unsurveyed territory; but inaccuracies necessarily accompany such procedure.

Where many samples are reported from areas as large as the 432-section quadrangles here used, it is difficult for the reader to visualize

conditions by transposing the data of the tables of analyses and location descriptions to their map positions. A detailed chemical analysis is essential to the adequate description of a water supply, but in the economic application of such analyses certain features are of greater importance than others. In formulating general conclusions with respect to the quality of water in an area it is convenient to adopt a system of group classification in order to clarify the major features. For the purposes here to be served, use is made of a trinomial exponent placed adjacent to each of the location numbers. Each of the figures of this trinomial exponent refers to a characteristic of the water sample. The first figure refers to the specific electrical conductance, the second to the concentration of boron, and the third to the percentage of sodium. The actual concentrations of these constituents are not represented, but instead a group classification is made on the basis of a scale of 1 to 5 for each of the three characteristics. The scale used for each is shown in table 8.

TABLE 8.—*Key to group classification of water samples with regard to specific electrical conductance, boron content, and sodium percentage, as represented by trinomial exponents shown on quadrangle maps*

Class	Conductance ($K \times 10^5$ at 25° C.)	Boron	"Percent sodium"
		P.p.m.	
1	Less than 25	Less than 0.25	Less than 20.
2	25 to 74.9	0.25 to 0.74	20 to 39.
3	75 to 149	0.75 to 1.49	40 to 59.
4	150 to 299	1.50 to 2.99	60 to 79.
5	300 and above	3.00 and above	80 and above.

A water having, for example, a conductance of 36, a boron content of 1.80 p.p.m., and a sodium percentage of 19 would be designated as 241. The classification is in part arbitrary, but it is clear that a water designated as 111 would be regarded as excellent, whereas a water designated 555 would be unsuitable for agricultural use. A water designated 533 might be used profitably under some conditions, whereas a 355 water would be expected in the end to cause the soil to become hard and impermeable with a tendency to accumulate toxic concentrations of salt in the soil solution.

If conductances are high, waters high in sodium are preferred for industrial or domestic use to those high in calcium and magnesium; but for agricultural use it is important that the sodium should be low relative to calcium and magnesium. For practically all purposes a water of low conductance, i.e., low total salinity, is preferable to one of high conductance. Boron concentrations too high for agricultural purposes may have little or no significance in waters used for domestic purposes, since there is no evidence that either people or animals would be adversely affected by the boron concentrations such as were found in the waters of the San Joaquin Valley.

ANALYTICAL DATA

The analytical data are presented in tables 9 to 39 and in the accompanying descriptions of samples, all arranged by quadrangles corresponding to the maps (figs. 3 to 32).

TABLE 9.—*Quality of water in quadrangle 1, Tps. 1, 2, 3, and 4 N., Rs. 1, 2, and 3 W. (fig. 3)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium" [1]
					$CO_3 + HCO_3$	Cl	SO_4	Ca	Mg	Alkali bases [1]	
				P.p.m.							
1	5062	Oct. 21, 1931	818	53.3	11.30	68.95	0.39	11.60	8.64	60.40	86
2	4571	July 10, 1931	89.9	.46	4.90	3.10	.72	3.26	3.61	2.15	24
3	4572	do	78.9	.33	5.10	1.45	2.03	3.62	1.37	3.60	42
4	4570	do	84.7	.22	4.65	2.10	1.22	2.87	3.69	1.95	23
5	6232	May 17, 1932	136	2.36	9.60	3.10	1.67	.33	.37	13.67	95
6	6230	do	78.4	3.93	6.95	1.30	.24	2.45	4.24	1.82	21
7	6231	do	80.4	1.62	4.50	2.40	1.55	2.14	3.13	3.22	38
8	6213	May 20, 1932	93.9	1.30	6.70	1.55	.81	3.63	3.26	2.89	30
Miscellaneous [2]	6239	May 18, 1932	44.0	.65	3.05	1.25	T [3]	1.14	.98	2.26	52
Do	6235	May 17, 1932	71.8	.66	6.55	.75	.44	3.19	2.72	1.83	24

[1] For method of computation see p. 39.
[2] Outside of quadrangle; included for convenience.
[3] T=trace.

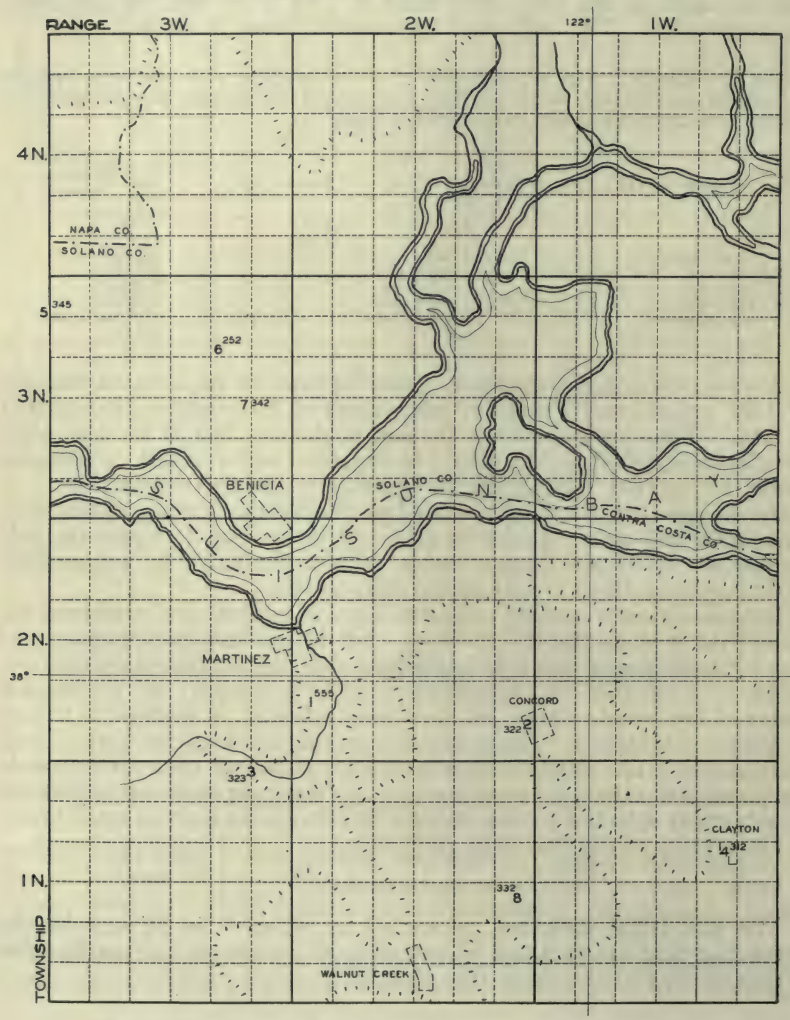

FIGURE 3.—Quadrangle 1, showing locations of samples reported in table 9.

DESCRIPTIONS OF SAMPLES OF QUADRANGLE 1 (TABLE 9 AND FIG. 3)

Location 1, sample 5062. F. W. Haag ranch, Martinez. Location corresponds to NE corner of SW¼ sec. 30, T. 2 N., R. 2 W. Depth about 40 feet. Collected by F. W. Herbert.

Location 2, sample 4571. Concord. Mrs. Amanda Smith, domestic well. Depth, 120 feet; static level, 80 feet.

Location 3, sample 4572. Alhambra Springs. Location corresponds to NW¼ sec. 1, T. 1 N., R. 3 W. Four springs discharging 10,000 gallons per day. Temperature, 60° F.

Location 4, sample 4570. Clayton. A. C. Trette well. NE¼ sec. 14, T. 1 N., R. 1 W. Depth, 70 feet.

Location 5, sample 6232. A. Garibaldi irrigation well. SE¼ sec. 1, T. 3 N., R. 4 W. An old oil well drilled to 2,700 feet, now partly caved in. Casing diameter, 3 inches; discharge, 0.04 cubic foot per second; temperature, 72° F.; some gas. Collected by V. W. De Tar.

Location 6, sample 6230. Sulphur Spring at mouth of Hastings Mine. SW¼ sec. 11, T. 3 N., R. 3 W. Discharge, 0.22 cubic foot per second; temperature, 73° F.; slight odor; discharge flows into Lake Herman, from which Benicia municipal supply is drawn. Collected by V. W. De Tar.

Location 7, sample 6231. Lake Herman. NE¼ sec. 23, T. 3 N., R. 3 W. Benicia municipal supply, with minor use for irrigation. In part from above-mentioned sulphur spring. Collected by V. W. De Tar.

Location 8, sample 6213. Bancroft ranch well, Ygnacio Valley. Approximately 3¾ miles south of Concord and 1 mile southwest of Whitman. Collected by R. E. Goble.

Miscellaneous sample 6239. Ralph Mason irrigation well. NE¼ sec. 35, T. 5 N., R. 3 W. 10-inch casing; depth, 134 feet; upper perforations, 20 feet; discharge, 0.7 cubic foot per second. Bailed sample, motor not operating. Collected by V. W. De Tar.

Miscellaneous sample 6235. J. B. Danielson irrigation well. NE¼ sec. 32, T. 5 N., R. 2 W. Depth, 180 feet; discharge, 0.33 cubic foot per second; temperature, 63° F. Collected by V. W. De Tar.

TABLE 10.—*Quality of water in quadrangle 2, Tps. 1, 2, 3, and 4 N., Rs. 1, 2, and 3 E. (fig. 4)*

Location no.	Sample no.	Date	$K \times 10^3$ at 25° C.	Boron	Milligram equivalents						"Percent sodium" [1]
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases [1]	
				P.p.m.							
1	4568	July 10, 1931	74.5	1.50	5.45	1.15	1.20	0.31	0.32	7.17	92
2	4565	do	40.0	.24	2.65	1.20	.21	.59	.71	2.76	68
	4566	do	297	1.44	4.00	23.40	.10	3.77	4.40	19.33	70
	4564	do	160	1.24	4.85	9.75	.43	1.56	2.06	11.41	76
3	4569	do	212	.81	6.50	4.30	12.97	6.12	5.22	12.43	52
4	2951	June 24, 1930	122	.43	5.50	1.85	5.61	3.56	3.34	6.05	47
5	2950	do	233	.39	6.75	5.30	13.62	4.04	7.38	14.25	56
6	2949	do	92.1	1.12	4.60	2.20	2.56	3.04	2.34	3.98	43
7	6202	May 20, 1932	84.1	.54	2.90	3.75	1.43	2.92	2.00	3.21	39
8	6204	do	113	1.48	4.50	4.55	2.39	3.79	2.81	4.99	43
9	6206	do	146	2.65	6.30	5.20	3.52	4.40	3.52	7.30	48
10	6203	do	103	1.29	5.10	3.15	2.34	3.83	3.05	3.87	36
11	6205	do	83.2	1.01	3.95	3.00	.97	2.93	1.92	3.14	39
12	6209	May 24, 1932	139	2.36	5.75	5.40	3.05	4.36	3.73	6.31	44
13	6208	do	141	2.20	5.60	5.55	3.38	4.27	3.73	6.59	45
	6210	May 27, 1932	136	2.34	5.40	5.35	3.33	3.92	3.74	6.42	46
14	5327	Oct. 28, 1931	114	2.16	5.68	3.90	2.17	3.90	2.90	5.06	43
15	5328	do	130	2.43	5.47	5.30	3.02	4.21	3.77	6.05	43
16–S	6212	Apr. 29, 1932	32.9	.34	1.30	1.15	.59	.87	.87	1.30	43
17	6207	May 20, 1932	141	3.27	5.45	5.55	3.34	3.72	3.59	7.07	49

[1] For method of computation see p. 39.

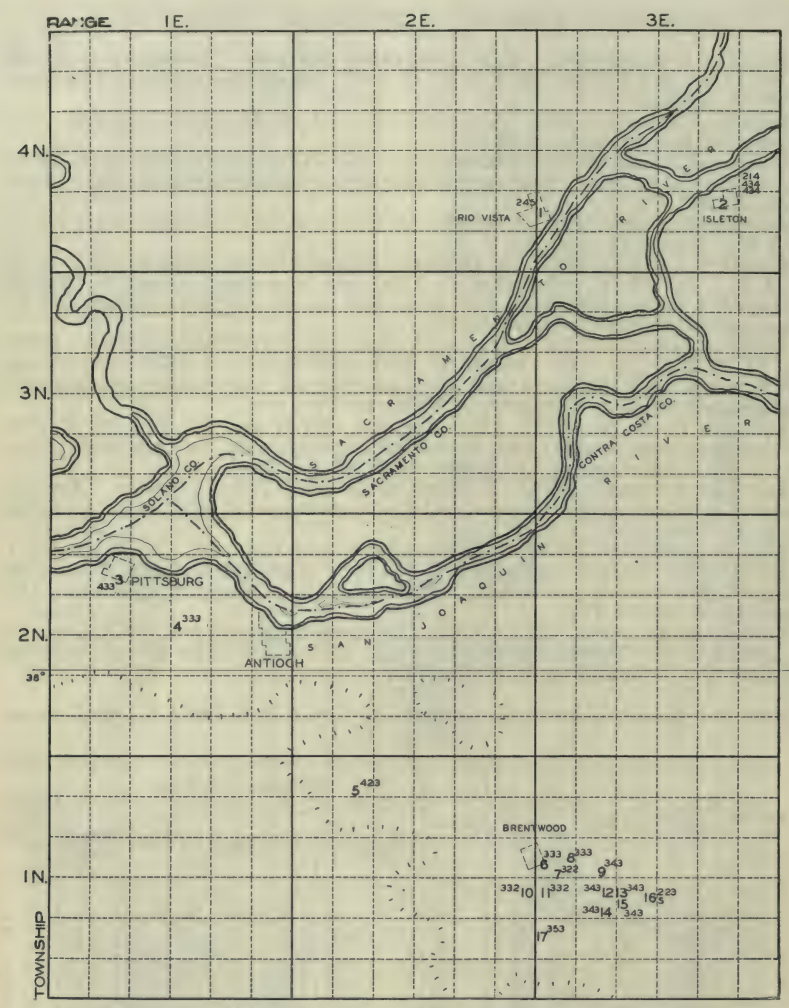

FIGURE 4.—Quadrangle 2, showing locations of samples reported in table 10.

DESCRIPTION OF SAMPLES OF QUADRANGLE 2 (TABLE 10 AND FIG. 4)

Location 1, sample 4568. Rio Fista municipal well; L. P. Gardiner, owner. Depth, approximately 250 feet.

Location 2, sample 4565. Isleton municipal, for fire emergency. Depth, 130 feet; 4-inch casing not perforated; water stands at 10 feet.

Location 2, sample 4566. Isleton municipal; L. P. Gardiner, owner. Seldom used because of sanding. Depth, 211 feet; 12-inch casing not perforated; water stands at 40 feet.

Location 2, sample 4564. Isleton municipal; L. P. Gardiner, owner. Depth, 615 feet; 10-inch casing not perforated; water stands at 60 to 70 feet. Approximately 70 feet from Sacramento River.

Location 3, sample 4569. Pittsburg municipal plant. Three wells 250 feet deep, perforated below 60 feet.

Location 4, sample 2951. Los Medanos Station, Standard Oil Co. Composite of three wells 157 to 171 feet deep, all perforated below about 140 feet.

Location 5, sample 2950. J. G. Pewetter, section 5, stock well. Center S½ sec. 5, T. 1 N., R. 2 E. Depth, about 30 feet.

Location 6, sample 2949. Brentwood municipal well. Depth, 180 feet.

Location 7, sample 6202. Balfour Guthrie Co. well. SW¼ sec. 18, T. 1 N., R. 3 E. Depth, 127 feet; static level, 45 feet; draws down to 93 feet; 12-inch casing perforated entire length. Collected by R. E. Goble.

Location 8, sample 6204. East Contra Costa Irrigation District. Drainage well on lateral 4. SW¼ sec. 19, T. 1 N., R. 3 E. Depth, 50 feet; static level, 12 feet; 16-inch casing. Collected by R. E. Goble.

Location 9, sample 6206. W. W. Collis well. SE¼ sec. 17, T. 1 N., R. 3 E., on Balfour Road. Depth, 48 feet; static level, 15 feet; casing diameter, 8 inches. collected by R. E. Goble.

Location 10, sample 6203. Balfour Guthrie Co. well. Brentwood irrigated farms, lot 50. NE¼ sec. 24, T. 1 N., R. 2 E. Depth, 116 feet; static level, 46 feet; draws down to 18 feet; irrigates 90 acres. Collected by R. E. Goble.

Location 11, sample 6205. R. B. Crawford well. Brentwood irrigated farms, lot 5. NW¼ sec. 19, T. 1 N., R. 3 E. Collected by R. E. Goble.

Location 12, samples 6209 and 6211. East Contra Costa Irrigation District, drainage well. SW¼ sec. 21, T. 1 N., R. 3 E. Collected by R. E. Goble.

Location 13, samples 6208 and 6210. East Contra Costa Irrigation District. Drainage well on main canal. SW¼ sec. 21, T. 1 N., R. 3 E. Collected by R. E. Goble.

Location 14, sample 5327. Andrew Davis, Jr., domestic well. Center south line SE¼ sec. 20, T. 1 N., R. 3 E. Depth, 50 feet; static level, 10.5 feet; draws down to 16 feet; discharge, 0.15 cubic foot per second. Casing extends through clay stratum excluding surface water and is not perforated. Collected by R. E. Goble.

Location 15, sample 5328. Andrew Davis, Jr., drainage well. Near NW corner SW¼ sec. 21, T. 1 N., R. 3 E. Depth, 35 feet; discharge, 1.5 cubic feet per second.

Location 16, sample 6212. East Contra Costa Irrigation District, main canal. Near W¼ corner sec. 21, T. 1 N., R. 3 E. Collected by R. E. Goble.

Location 17, sample 6207. H. P. Garin Co. well no. 5. Near SW corner NW¼ sec. 30, T. 1 N., R. 3 E. Depth, 600 feet; static level, 125 feet. Collected by R. E. Goble.

TABLE 11.—*Quality of water in quadrangle 3, Tps. 1, 2, 3, and 4 N., Rs. 4, 5, and 6 E. (fig. 5)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	4562	July 10, 1931	45.8	1.06	4.45	0.45	T [1]	0.79	0.35	3.76	77
2–8	4560	do	6.41	.06	.55	.05	0.03	.30	.11	.22	35
3	4559	do	28.2	.08	2.15	.30	.20	1.09	1.08	.51	19
4	3416	Oct. 13, 1930	176	.12	1.05	14.35	T	4.06	2.13	9.21	60
5	4543	July 8, 1931	32.2	.10	2.80	.30	.21	1.17	.86	1.49	42
6	4544	do	39.4	.16	2.70	.55	.42	1.89	1.26	.84	21
7	4542	do	35.5	.66	3.15	.55	.03	.32	.17	3.24	87
8	4539	do	971	2.40	1.65	92.50	T	26.11	13.01	55.03	58
9	2944	June 24, 1930	24.9	.20	2.20	.20	.12	.38	.44	1.70	67
	3454	Oct. 24, 1930	22.7	.05	1.75	.05	.01	.57	.51	.73	40
	3692	Jan. 19, 1931	23.7	.07	1.90	.20	.03	.50	.31	1.32	62
	4540	July 8, 1931	23.9	.14	2.30	.25	.04	.48	.40	1.71	66
	3417	Oct. 13, 1930	27.2	.36	2.70	.25	.06	.22	.24	2.55	85
	3529	Nov. 4, 1930	27.5	.37	2.55	.25	.05	.77	.25	1.83	64
10	4545	July 8, 1931	1,258	2.58	1.15	121.50	.04	43.42	11.72	67.55	55
11	4546	do	140	1.18	3.35	9.35	.01	1.82	1.60	9.30	73
12	4541	do	62.0	.83	3.45	2.80	.08	1.15	.88	4.31	68
13	4547	do	72.0	.38	3.00	3.90	.06	2.14	1.25	3.60	52
Miscellaneous [2]	4563	July 10, 1931	47.8	.95	4.90	.40	T	.35	T	4.95	93

[1] T=trace.

[2] Outside of quadrangle; included for convenience.

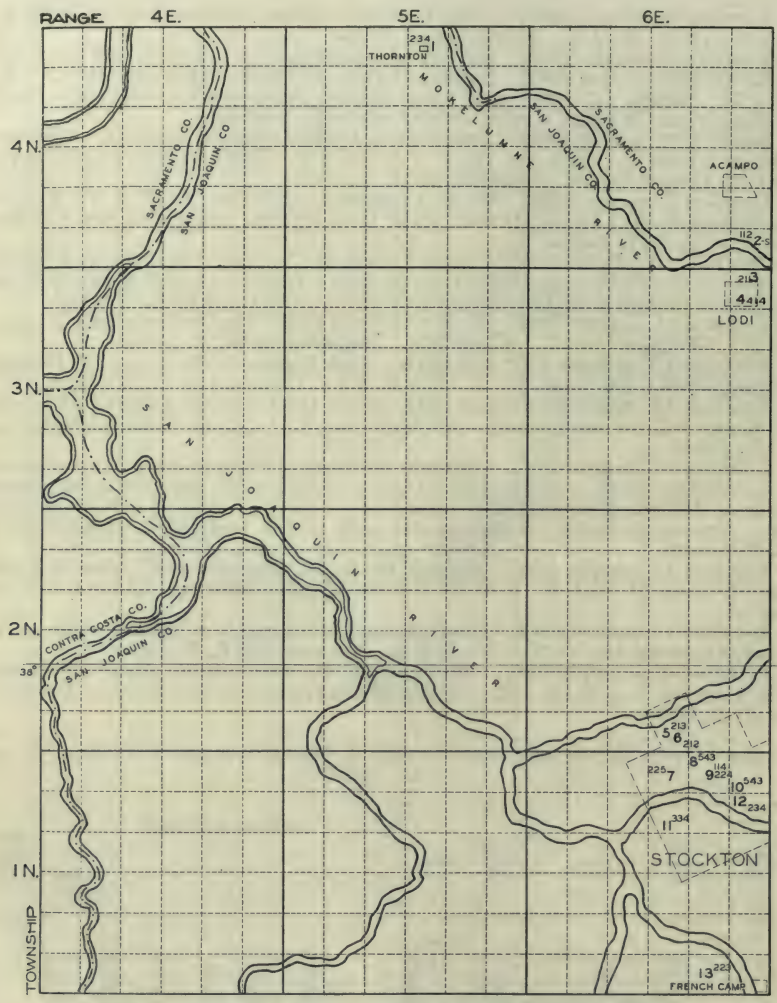

FIGURE 5.—Quadrangle 3, showing locations of samples reported in table 11.

DESCRIPTION OF SAMPLES OF QUADRANGLE 3 (TABLE 11 AND FIG. 5)

Location 1, sample 4562. Western Pacific depot, Thornton. Depth, 280 feet; 14-inch casing.

Location 2–S, sample 4560. Mokelumne River, near Lodi.

Location 3, sample 4559. Vita Fruit Products Co. well, approximately 1 mile north of Lodi. Depth, 150 feet.

Location 4, sample 3416. Lodi municipal well. Used forbath house. Depth, 1,900 feet; temperature, 68° F.; high gas content; formerly flowing, now operated by small pump. Collected by C. S. Scofield.

Location 5, sample 4543. Stockton municipal. California Water Service Co. plant no. 4, at Ellis Street, two blocks west of North Center Street. Depth, 533 feet.

Location 6, sample 4544. Shallow domestic well. East Geary and North Center Streets; near sample 4543. Depth, 101 feet; static level about 75 feet.

Location 7, sample 4542. Stockton municipal. California Water Service Co., plant no. 2, at Monroe and Poplar Streets. Composite of three wells, each about 700 feet deep.

Location 8, sample 4539. Gas well at Hunter Street and Harding Way. Pacific Gas & Electric Co. Water supplies high-school plunge. An old well drilled to 2,900 feet. Temperature, 88° F.

Location 9, samples 2944, 3454, 3692, 4540. Stockton State Hospital, 1,000 block, North California Street. Depth, 594 feet; discharge, 1,000 gallons per minute; temperature, 64° F.

Location 9, samples 3417, 3529. Stockton State Hospital, new well. Depth, 624 feet; discharge, 2 cubic feet per second.

Location 10, sample 4545. Gas well, Wilson Way and Minor Avenue. Depth, 3,300 feet; temperature, 96° F. Serves Olympic Baths.

Location 11, sample 4546. Fibreboard Products, Inc., Stockton, West Church Street, one-quarter mile west of Lincoln Street. Well no. 2. Depth, 1,040 feet; perforated below 233 feet; water stands at 21 feet.

Location 12, sample 4541. Stockton municipal. California Water Service Co., plant no. 1, at East Sonora Street and Wilson Way. Composite of eight wells; depth, 670 to 1,070 feet; none perforated above 200 feet; discharge, each, 2.2 cubic feet per second.

Location 13, sample 4547. San Joaquin County Hospital, one-half mile west of French Camp. Depth, 228 feet; perforated below 185 feet; water stands at 17 feet.

Miscellaneous sample 4563. Walnut Grove. Well at Alexander Brown Hotel, T. 5 N., R. 5 E. Depth, 189 feet.

TABLE 12.—*Quality of water in quadrangle 4, Tps. 1, 2, 3, and 4 N., Rs. 7, 8, and 9 E. (fig. 6)*

Location no.	Sample no.	Date	$K \times 10^6$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1-S	4560	July 10, 1931	6.41	0.06	0.55	0.05	0.03	0.30	0.11	0.22	35
2	4556	July 9, 1931	65.6	.07	3.00	2.65	.24	2.03	2.28	1.75	29
3	4558	July 10, 1931	60.1	.10	3.20	1.15	.21	2.77	2.16	1.06	18
4	4557	July 9, 1931	32.4	.06	2.70	.20	.26	1.38	1.35	.47	15
5	4555	July 10, 1931	25.2	.06	2.45	.10	.09	1.22	.93	.54	20
6	4554	do	20.0	.04	1.50	.25	.06	.76	.71	.51	26

DESCRIPTION OF SAMPLES OF QUADRANGLE 4 (TABLE 12 AND FIG. 6)

Location 1, sample 4560. Mokelumne River near Lodi.

Location 2, sample 4556. Clements municipal water.

Location 3, sample 4558. George Messner well. NW¼ sec. 31, T. 3 N., R. 7 E. Depth, 108 feet; stands 40 feet.

Location 4, sample 4557. W. B. Parker well. S½ sec. 35, T. 3 N., R. 7 E. Depth, 265 feet; perforated at all strata.

Location 5, sample 4555. F. W. Moznett well, Linden. SE¼ sec. 15, T. 2 N., R. 8 E. Depth, 288 feet; perforated below 30 feet; water stands at 46 feet.

Location 6, sample 4554. Toda Bros. well. SE¼ sec. 16, T. 1 N., R. 9 E. Depth, 180 feet, not perforated.

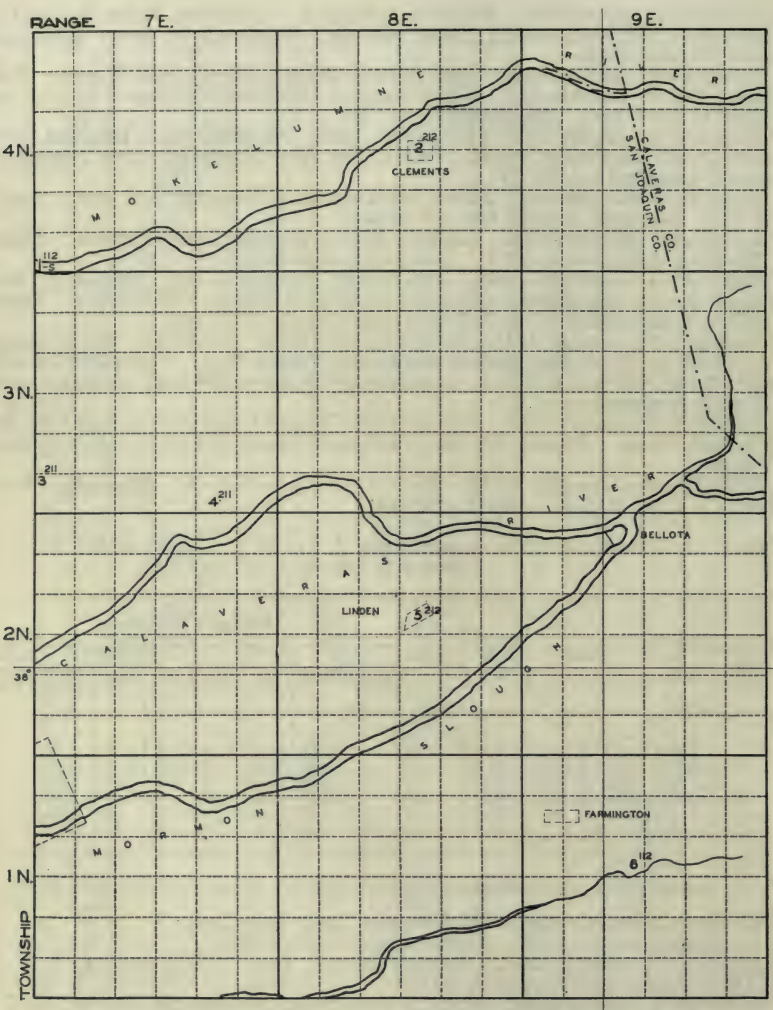

FIGURE 6.—Quadrangle 4, showing locations of samples reported in table 12.

TABLE 13.—*Quality of water in quadrangle 5, Tps. 1, 2, 3, and 4 S., Rs. 1, 2, and 3 E. (fig. 7)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	2948	June 24, 1930	121	2.06	6.95	3.60	2.06	3.43	3.19	5.99	48
2	2947	do	177	5.24	8.85	9.10	2.14	1.42	1.09	17.58	88
3	6350	June 22, 1932	164	1.90	6.70	7.65	1.01	3.80	3.22	9.63	58
4	6349	do	401	20.5	8.50	29.90	T [1]	.70	.42	37.29	97
5	6352	do	51.1	.21	4.15	.65	.61	2.55	2.13	.87	16
6	6351	do	68.3	.32	5.95	.95	.81	2.20	4.18	1.51	19
7–S	6353	do	22.1	.11	1.75	.20	.20	1.16	.75	.27	12

[1] T=trace.

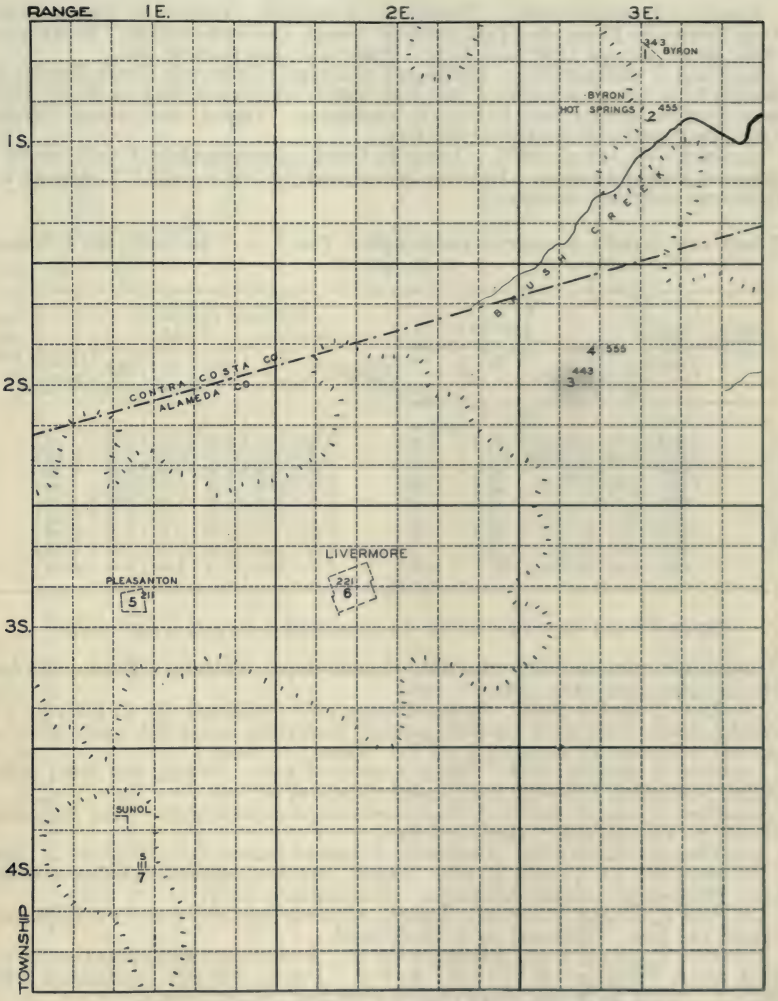

FIGURE 7.—Quadrangle 5, showing locations of samples reported in table 13.

DESCRIPTION OF SAMPLES OF QUADRANGLE 5 (TABLE 13 AND FIG. 7)

Location 1, sample 2948. Byron, Southern Pacific depot. Depth, 40 feet; water stands at 10 feet.

Location 2, sample 2947. Byron Hot Springs, "white sulphur spring." Temperature 81° F. Free H_2S reported as 16.7 cc per liter.

Location 3, sample 6350. Southern Pacific depot, Altamont, from well three-fourths mile west. Near center south line SW¼ sec. 17, T. 2 S., R. 3 E. Depth not known; static level, 15 feet; agent believes water drawn from 125-foot level. Cool, without odor or gas. Used sparingly in locomotives.

Location 4, sample 6349. Summit Garage, Altamont (Tesla quadrangle). Near SE corner NE¼ sec. 17, T. 2 S., R. 3 E. Old oil well drilled by Standard Oil Co. Original depth, 1,190 feet, possibly partly filled in now. Outer casing 12 inches; water-pump casing 1½ inches extending to 250 feet; static level, 175 feet; windmill pump. Water cold, slight odor with CO_2 and possibly other gases.

Location 5, sample 6352. Pleasanton municipal. From San Francisco city wells located in Pleasanton just north of Arroyo Del Valle bridge. A battery of wells, some perhaps 1,000 feet deep. Static level less than 28 feet.

Location 6, sample 6351. Livermore municipal, California Water Service Co. Sample from tap; composite of two wells within city limits, first on North Livermore Avenue, second near P. G. & E. substation. Depth, each, about 600 feet, with upper perforations below 100 feet.

Location 7–S, sample 6353. Alameda Creek, approximately 1 mile south of Sunol, at highway bridge. Location corresponds to NW¼ sec. 21, T. 4 S., R. 1 E. Discharge unknown but small.

TABLE 14.—*Quality of water in quadrangle 6, Tps. 1, 2, 3, and 4 S., Rs. 4, 5, and 6 E. (fig. 8)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	4552	July 9, 1931	41.5	0.18	2.70	1.15	0.19	1.61	0.88	1.64	40
2	2945	June 24, 1930	380	5.52	5.45	14.85	18.69	5.19	7.18	26.62	68
3	2946	do	68.0	1.12	3.05	1.30	2.45	2.45	1.39	2.96	44
4	4550	July 9, 1931	98.8	.89	2.35	2.25	4.89	3.60	2.32	4.25	42
5	4551	do	89.8	.82	2.70	1.80	4.37	1.59	1.61	5.75	64
6	3419	Oct. 13, 1930	102	.79	2.45	3.70	3.73	3.54	2.61	3.73	38
7	4549	July 9, 1931	56.9	.62	3.85	.55	1.72	2.41	1.30	2.75	43
8	3294	Sept. 19, 1930	59.5	.37	3.45	1.00	2.20	2.78	1.55	2.32	35
9	6348	June 22, 1932	207	3.02	6.00	9.65	5.72	3.10	5.61	12.80	60

DESCRIPTIONS OF SAMPLES OF QUADRANGLE 6 (TABLE 14 AND FIG. 8)

Location 1, sample 4552. Southern Pacific depot, Lathrop. Depth, 160 feet; 7-inch casing; drilled in 1896.

Location 2, sample 2945. Fabian flowing well. SE¼ sec. 33, T. 2 S., R. 4 E. Depth, about 2,000 feet; 14-inch casing; discharge, about 0.1 cubic foot per second; temperature, estimated, 86°F. Water not used.

Location 3, sample 2946. Tracy municipal well. Depth, 215 feet; 8-inch casing, perforated below 42 feet; water stands at 21 feet.

Location 4, sample 4550. J. C. Casselman, domestic well. Near SE corner sec. 25, T. 2 S., R. 5 E. Depth, 90 feet.

Location 5, sample 4551. California Irrigated Farms, Inc., well no. 1. Near NW corner sec. 18, T. 2 S., R. 6 E. Depth, 654 feet; perforated below 618 feet; flows, pumped to increase discharge. Temperature, 71°F.

Location 6, sample 3419. Lou Dedini, domestic well. Sec. 2, T. 3 S., R. 5 E. Depth, 145 feet. Collected by C. S. Scofield.

Location 7, sample 4549. Standard Oil Co., Vernalis pumping plant well no. 2. West center SW¼ sec. 35, T. 3 S., R. 6 E. Depth, 270 feet; perforated below 100 feet; stands at 76 feet; draws down to 98 feet; 8-inch casing.

Location 8, sample 3294. El Solyo Ranch, plant no. 2. Near SW corner sec. 1, T. 4 S., R. 6 E. Depth, 129 feet; stands 57 feet; discharge, 0.4 cubic foot per second.

Location 9, sample 6348. Mountain House well. Near center S½ sec. 18, T. 2 S., R. 4 E. A shallow well with brick casing; static level, about 12 feet. Supplies service station.

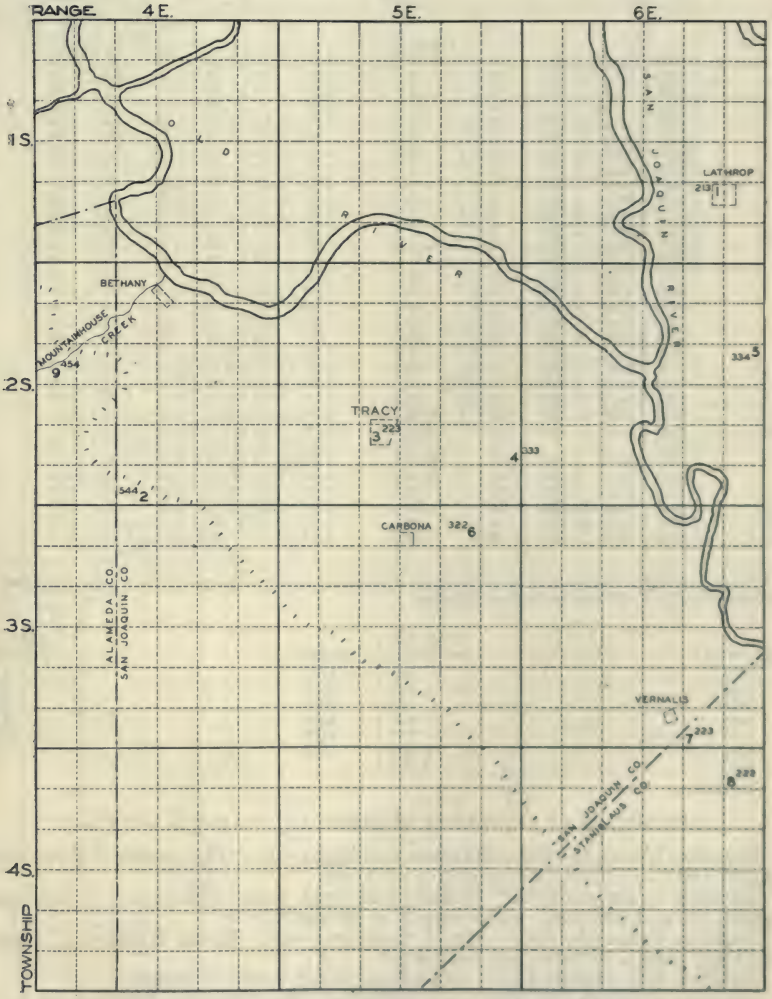

FIGURE 8.—Quadrangle 6, showing locations of samples reported in table 14.

TABLE 15.—*Quality of water in quadrangle 7, Tps. 1, 2, 3, and 4 S., Rs. 7, 8, and 9 E. (fig. 9)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	4538	July 7, 1931	34.5	0.12	2.55	0.45	0.16	1.72	1.03	0.65	19
2	4553	July 10, 1931	44.0	.08	3.60	.40	.35	1.88	1.62	1.39	28
3	4537	July 7, 1931	43.8	.15	2.65	.70	.18	1.67	.91	1.66	39
4–S	4536	do	23.0	.06	1.95	.15	.04	1.05	.75	.41	19
5–S[1]	1367	June 21, 1929	65.3	.18	2.16	2.64	1.55	1.87	1.54	2.94	46
	3296	Sept. 19, 1930	36.9	.03	1.80	1.80	.42	1.02	1.06	1.94	48
	4579	July 16, 1931	68.3	.23	2.45	3.40	.37	1.89	1.41	2.97	47
	4780	Aug. 1, 1931	72.3	.12	2.65	3.90	.27	1.94	1.47	3.44	50
	4827	Sept. 1, 1931	58.6	.13	2.45	2.80	.32	1.58	.90	3.13	56
	4966	Oct. 1, 1931	59.4	.09	2.45	2.80	.42	1.69	1.41	2.63	46
	5129	Nov. 2, 1931	78.3	.22	2.25	3.65	.74	1.93	1.72	3.03	45
	5329	Dec. 1, 1931	78.6	.21	2.26	3.70	1.46	1.96	1.86	3.64	49
	5387	Jan. 1, 1932	21.7	.11	.80	.50	.21	.64	.78	.24	14
	5602	Feb. 1, 1932	19.1	.07	.95	.50	.24	.67	.49	.59	52
	5773	Mar. 1, 1932	22.3	.03	1.15	.60	.68	.70	.62	1.16	47
	5883	Apr. 1, 1932	38.4	.09	1.30	1.60	.70	1.11	.96	1.59	43
	6099	May 2, 1932	27.0	.23	1.05	1.05	.45	.75	.93	.93	36
	6226	June 1, 1932	11.3	.03	.50	.30	.18	.41	.54	.04	4
	6479	July 1, 1932	11.3	.03	.75	.30	.11	.32	.21	.66	55
	6539	Aug. 1, 1932	70.5	.21	2.15	3.40	1.19	1.77	1.65	3.32	49
6	3420	Oct. 14, 1930	71.0	.80	3.20	1.25	2.75	2.02	1.91	3.27	45
7	4535	July 7, 1931	36.0	.14	2.20	1.00	.02	1.52	.76	1.05	32
8	3293	Sept. 19, 1930	75.6	.70	3.60	2.05	2.30	2.41	1.77	3.77	47
9	3349	July 27, 1930	232	3.60	4.10	4.25	17.52	7.79	5.99	12.09	47
10	2942	June 23, 1930	90.6	1.25	3.70	2.35	3.15	2.78	2.31	4.11	45
11	2943	do	341	3.22	1.85	10.50	22.69	8.14	10.22	16.68	48
	4826	Sept. 8, 1931	328	4.60	4.70	10.20	21.57	6.94	10.00	19.71	54
	5114	Nov. 2, 1931	319	4.49	4.80	9.85	20.71	6.97	9.51	19.04	54
12–S	4750	Aug. 1, 1931	138	.45	3.50	5.95	4.19	3.22	3.51	6.94	51
13	2940	June 23, 1930	106	.53	3.90	3.20	3.51	2.37	5.53	2.71	26
14	6347	June 22, 1932	88.1	.27	7.75	1.60	T[2]	2.21	1.04	6.31	66
15	6660	Sept. 1, 1932	63.5	.40	4.85	1.15	.30	1.91	1.27	3.41	52

[1] Discharges of San Joaquin River at El Solyo diversion, below the mouth of the Tuolumne River, as estimated by W. F. Wooley at time of sampling:

Sample no.:	*Cubic feet per second*	Sample no.:	*Cubic feet per second*
4579	300	5773	2,000
4780	135	5883	1,000
4827	150	6099	5,000
4966	250	6226	15,000
5329	760	6479	15,000
5387	3,000	6539	800
5602	3,500		

[2] T=trace.

DESCRIPTION OF SAMPLES OF QUADRANGLE 7 (TABLE 15 AND FIG. 9)

Location 1, sample 4538. Manteca municipal wells. Composite of three wells; depth, 140 to 150 feet; water stands at 6 feet.

Location 2, sample 4553. Escalon municipal wells. Composite of two wells; depth, 150 and 250 feet; water stands at 10 feet.

Location 3, sample 4537. Ripon municipal well. Ripon Water Co. Depth, 186 feet; stands 18 feet; not perforated.

Location 4–S, sample 4536. Stanislaus River, south of Ripon.

Location 5–S, samples 1367 and following. San Joaquin River at El Solyo Ranch diversion, below mouth of Tuolumne River. Collected by Leonard Petersen.

Location 6, sample 2420. El Solyo Ranch, Brigham Place, domestic well. Collected by C. S. Scofield.

Location 7, sample 4535. Modesto municipal water. Tap at Ninth and I Streets.

Location 8, sample 3293. El Solyo Ranch well at Camp 2. Depth, 165 feet; stands at 28 feet.

Location 9, sample 3349. El Solyo Ranch well at old Camp 1. Collected by R. M. Pike.

Location 10, sample 2942. El Solyo Ranch well at Oaklea headquarters. Depth, 115 feet.

Location 11, samples 2943, 4826, and 5114. El Solyo Ranch well at dairy. Depth, 115 feet.

Location 12–S, sample 4750. San Joaquin River, Laird's Slough, 1 mile above mouth of Tuolumne. At the time of this sample the water was largely if not

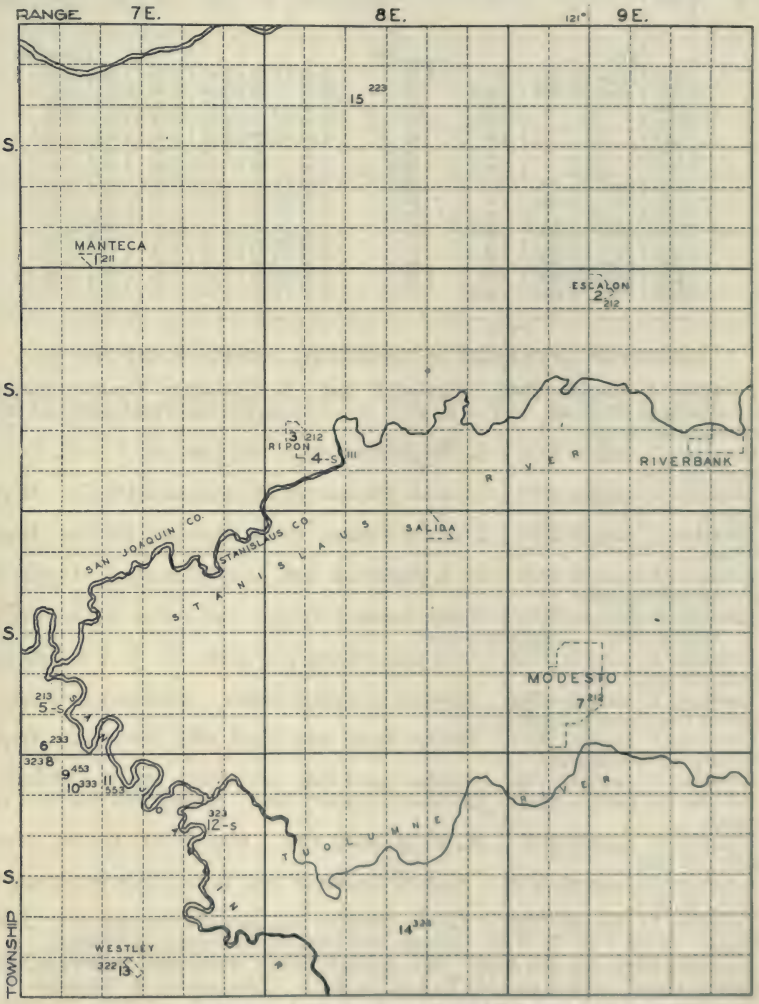

FIGURE 9.—Quadrangle 7, showing locations of samples reported in table 15.

entirely return flow and drainage from irrigated lands above. Discharge, 35 cubic feet per second.

Location 13, sample 2940. Westley, well at Benson Garage. Depth, 73 feet.

Location 14, sample 6347. F. C. Roberts, domestic and garden well. S½SE¼-NW¼ sec. 27, T. 4 S., R. 8 E. Depth, 125 feet; upper perforations, 100 feet; casing diameter, 7 inches; temperature, 64°F.; water clear, no odor.

Location 15, sample 6660. P. G. Poynor spring. SW¼ sec. 9, T. 1 S., R. 8 E. Spring issues into pond 150 feet in diameter. Water cool and clear; used for stock. Spring runs low during summer months but always flows. Collected by W. J. Murphy.

TABLE 16.—*Quality of water in quadrangle 8, Tps. 5, 6, 7, and 8 S., Rs. 7, 8, and 9 E. (fig. 10)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	2941	June 23, 1930	137	0.53	4.65	6.00	3.85	2.75	7.16	4.59	32
2	2787	May 23, 1930	80.7	.47	2.70	2.70	2.10	1.69	3.04	2.77	37
3	2786	do	177	.66	2.35	2.10	14.63	3.88	5.97	9.23	48
	2785	do	73.4	.47	3.20	.45	3.51	1.81	2.61	2.74	38
4	2784	do	139	.67	3.30	3.00	7.79	5.01	4.66	4.42	31
5	2788	do	63.0	.29	3.95	.35	2.09	2.37	1.16	2.86	45
6	2783	do	96.6	.52	7.60	1.60	.95	3.00	2.61	4.54	45
7	3292	Sept. 18, 1930	101	.46	3.90	3.40	3.02	3.17	2.91	4.24	41
	1955	Oct. 8, 1929	112	.98	3.00	5.95	1.85	1.74	1.80	7.26	67
8	1954	do	68.0	.46	3.55	1.05	2.41	2.50	1.67	2.84	41
	2782	May 23, 1930	86.4	.38	3.25	1.40	3.89	2.21	2.16	4.17	49
9	1956	Oct. 8, 1929	112	.64	6.90	2.25	2.98	4.91	1.73	5.49	45
10	2781	May 23, 1930	131	.54	5.65	2.95	3.62	5.57	2.52	4.13	34
11	3291	Sept. 18, 1930	115	1.08	3.50	5.90	2.07	1.63	1.78	8.06	70
12–S	3428	Oct. 1, 1930	84.8	.17	2.50	4.25	1.64	1.86	1.62	4.91	59

DESCRIPTION OF SAMPLES OF QUADRANGLE 8 (TABLE 16 AND FIG. 10)

Location 1, sample 2941. Signoretti well, El Pascadero Grant. Location corresponds to SW¼ sec. 1, T. 5 S., R. 7 E. Depth, 369 feet; perforated at seven water-bearing strata.

Location 2, sample 2787. L. W. Johnson well. W½ sec. 19, T. 5 S., R. 8 E. Depth, 60 feet.

Location 3, sample 2786. Emerald Station, well 3, Standard Oil Co. Depth, 240 feet.

Location 3, sample 2785. Emerald Station, well 4, Standard Oil Co. Depth, 370 feet.

Location 4, sample 2784. F. T. McGinnis well, Crows Landing. Depth, 208 feet; not perforated.

Location 5, sample 2788. Walter Isman, irrigation well. Near S¼ corner, sec. 3, T. 7 S., R. 8 E. Depth, 260 feet.

Location 6, sample 2783. Well near center NW¼ sec. 18, T. 7 S., R. 9 E. Depth, 40 feet.

Location 7, sample 3292. Newman municipal wells. Collected from tap at P Street Grammar School.

Location 7, sample 1955. Golden State milk plant well, Newman. Depth, 425 feet; not perforated.

Location 8, sample 1954. Gustine municipal, new well. Depth, 150 feet.

Location 8, sample 2782. Gustine Creamery well. Depth, 225 feet; not perforated.

Location 9, sample 1956 W. K. McBride well. W½ sec. 17, T. 8 S., R. 9 E. Depth, 35 feet.

Location 10, sample 2781. Shallow domestic well, near center NE¼ sec. 30, T. 8 S., R. 9 E.

Location 11, sample 3291. Lenora Station, Associated Pipe Line Co. NE¼-SE¼ sec. 28, T. 8 S., R. 9 E. Depth, 450 feet; water stands at 12 feet.

Location 12–S, sample 3428. San Joaquin River, Patterson Water Co., main diversion canal. SW¼ sec. 15, T. 5 S., R. 8 E. Collected by R. Schmidt.

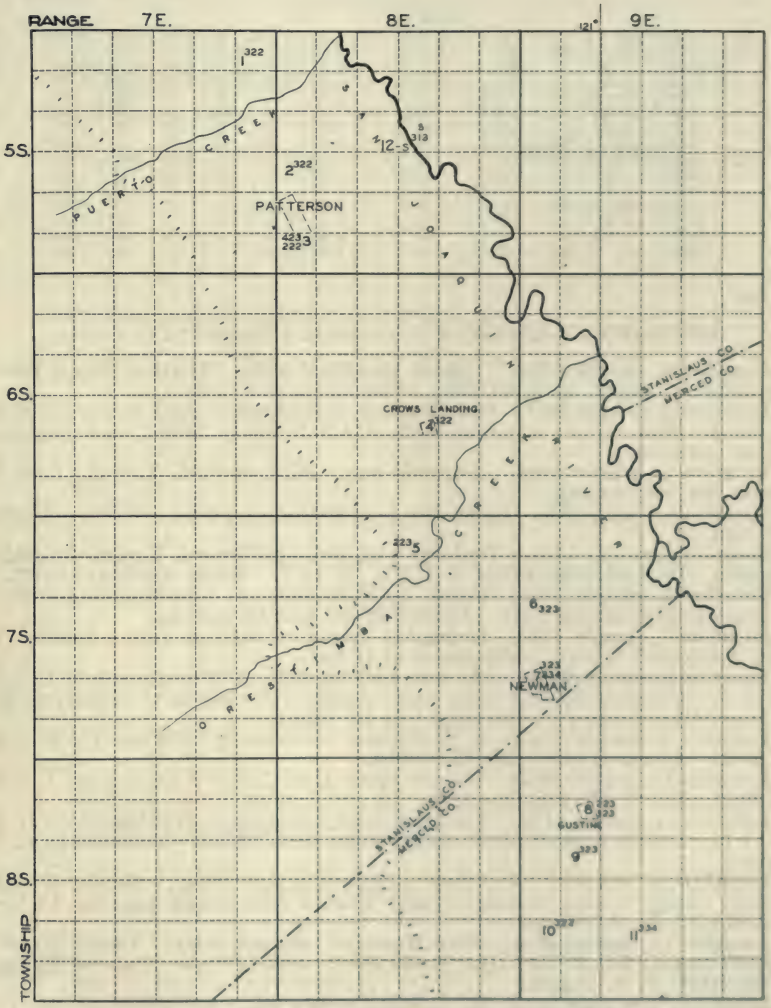

FIGURE 10.—Quadrangle 8, showing locations of samples reported in table 16.

TABLE 17.—*Quality of water in quadrangle 9, Tps. 5, 6, 7, and 8 S., Rs. 10, 11, and 12 E. (fig. 11)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m							
1	4534	July 7, 1931	44.9	0.13	3.55	0.40	0.29	2.34	1.26	1.03	22
2	2937	June 23, 1930	273	2.64	2.45	12.90	10.95	3.30	.96	22.04	84
3	2938	do	234	(1)	2.65	9.75	10.50	3.43	1.14	18.33	80
	2939	do	270	2.73	2.55	12.95	10.86	3.88	1.03	21.45	81
4	1369	June 21, 1929	24.0	.14	1.37	.31	.20	.90	.38	.60	32
5	1370	do	5.0	.02	.33	.36	.08	.16	.03	.58	75
6–S	1371	do	16.2	.08	1.22	.15	.16	.61	.22	.70	46
7	4533	July 7, 1931	27.3	.02	1.65	.40	.12	.90	.57	1.16	44
8	2936	June 23, 1930	440	.70	1.50	37.50	1.48	9.30	2.05	29.13	72
9	2935	do	20.3	.15	1.80	.20	.34	1.19	.34	.81	35
10	2933	do	47.6	.07	3.80	1.05	.39	.45	.15	4.64	89
11	6159	May 24, 1932	27.0	.05	1.85	.25	.14	.72	.52	1.46	54
	6160	do	17.1	.03	1.55	.25	.09	.49	.29	1.11	59
	6161	do	32.4	.07	2.05	.55	.20	1.02	.66	1.62	49
12	6634	Aug. 24, 1932	86.5	.26	6.20	2.40	.33	.50	.68	7.96	87

[1] Lost.

DESCRIPTION OF SAMPLES OF QUADRANGLE 9 (TABLE 17 AND FIG. 11)

Location 1, sample 4534. Turlock municipal wells. Marshall Street plant, seven wells. Depth, 40 to 300 feet; water stands at 14 feet.

Location 2, sample 2937. Old Stevinson well (Reed). SE¼ sec. 31, T. 6 S., R. 10 E. One of two adjacent wells which formerly flowed, now pumped. Depth not known.

Location 3, sample 2938. Richards well. NE¼ sec. 36, T. 7 S., R. 9 E. Depth 356 feet; flowing.

Location 3, sample 2939. Beckworth well; 250 feet east of sample 2938. Depth, 300 feet.

Location 4, sample 1369. Drainage well, Delhi Settlement, Turlock Irrigation District. In or adjacent to sec. 2; T. 6 S., R. 11 E. Water stands at 20 feet.

Location 5, sample 1370. Canal, Delhi Settlement. Opposite sample 1369.

Location 6–S, sample 1371. Merced River, near Livingston.

Location 7, sample 4533. Livingston municipal wells; 2 wells. Depth, 157 feet; perforated casings; water stands at 16 feet.

Location 8, sample 2936. Old deep well (Rosa). NW corner sec. 2, T. 7 S., R. 10 E. Formerly flowed; casing badly rusted; water stands at 12 feet; sample obtained from 2-inch pipe extending into old casing.

Location 9, sample 2935. J. F. Rhodes, Stevinson. NE¼ sec. 15, T. 7 S., R. 10 E. Domestic well. Depth, 45 feet.

Location 10, sample 2933. Charles Lyons Gun Club. NE¼ sec. 28, T. 7 S., R. 10 E. Depth, 265 feet; flowing.

Location 11, sample 6159. Vern Hammatt, house well. NE¼ sec. 25, T. 6 S., R. 11 E. Depth, 60 feet; 7-inch casing; static level, 10 feet. Collected by R. V. Wright.

Location 11, sample 6160. Vern Hammatt, grove pump. Depth, 47 feet; 12-inch casing; 6-inch discharge; static level, 7 feet; draws down to 15 feet. Collected by R. V. Wright.

Location 11, sample 6161. Vern Hammatt, electric pump. Depth, 70 feet; 12-inch casing; 6-inch discharge; static level, 15 feet; draws down to 27 feet. Collected by R. V. Wright.

Location 12, sample 6634. L. T. Mark ranch well. NE¼NE¼ sec. 21, T. 7 S., R. 10 E. Depth, 24 feet; 3-inch pump. Collected by Wallace Sullivan.

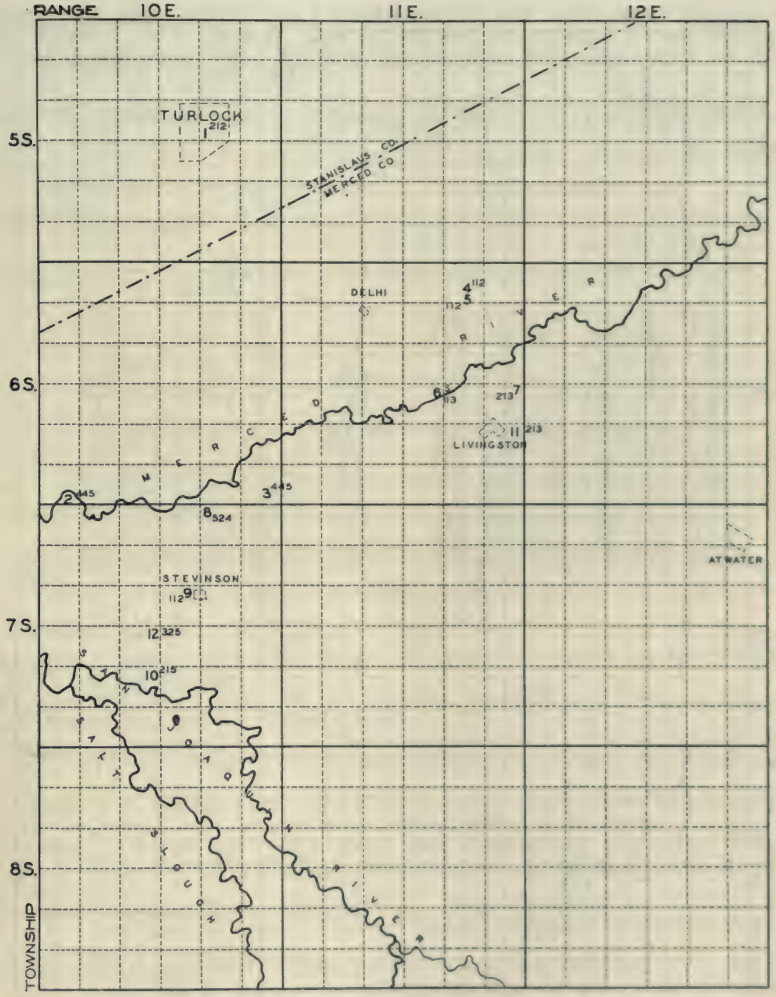

FIGURE 11.—Quadrangle 9, showing locations of samples reported in table 17.

TABLE 18.—*Quality of water in quadrangle, 10, Tps. 9, 10, 11, and 12 S., Rs. 7, 8, and 9 E. (fig. 12)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m							
1	1953	Oct. 8, 1929	515	2.74	3.30	6.75	38.07	15.40	23.73	28.99	43
2	3289	Sept. 18, 1930	130	1.48	4.55	4.50	4.07	2.87	4.49	5.76	44
3	3290	do	202	1.99	3.10	10.80	6.71	4.46	3.89	12.26	59
4	2789	May 23, 1930	54.2	.37	4.45	.50	.39	1.99	1.66	1.69	32
5–S	2791	do	99.7	.55	4.60	4.15	1.14	2.51	2.79	4.59	45
6	2780	do	132	.96	4.60	6.50	1.85	2.68	3.70	6.87	51
7	2779	do	52.3	.47	3.30	1.00	.85	1.50	1.37	2.28	44
8	2790	do	254	.69	3.05	6.70	17.84	6.40	8.23	12.96	47

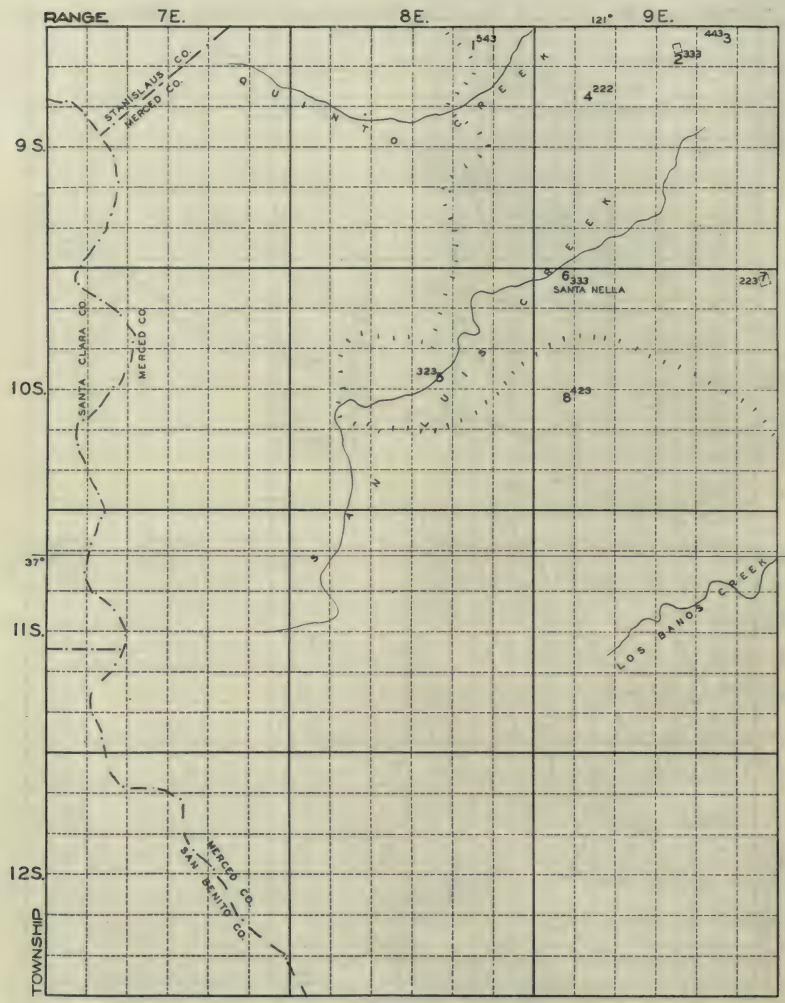

FIGURE 12.—Quadrangle 10, showing locations of samples reported in table 18.

DESCRIPTION OF SAMPLES OF QUADRANGLE 10 (TABLE 18 AND FIG. 12)

Location 1, sample 1953. Allen Ranch. Stock well at mouth of an arroyo near center sec. 2, T. 9 S., R. 8 E. Depth, 360 feet; flows with very small stream to supply trough.

Location 2, sample 3289. Ingomar section house, domestic well. Depth, 90 feet; perforated below 80 feet; stands at 8 feet.

Location 3, sample 3290. Salinas Gun Club. NE¼ sec. 2, T. 9 S., R. 9 E. New flowing well; depth, 550 feet; upper 100 feet of casing is 16-inch, remainder 12-inch; upper perforations, 420 feet; ground water encountered at 9 feet.

Location 4, sample 2789. Shallow domestic well, Quinto Creek delta. SW¼ sec. 8, T. 9 S., R. 9 E.

Location 5–S, sample 2791. San Luis Creek at Pacheco Pass highway crossing. SE¼ sec. 15, T. 10 S., R. 8 E. Discharge, 0.02 cubic foot per second.

Location 6, sample 2780. Santa Nella, domestic well. NE corner sec. 6, T. 10 S., R. 9 E. Depth, 90 feet; water-bearing gravel reported only at 52 feet; casing not perforated elsewhere.

Location 7, sample 2779. Joe Vallado, domestic well. Opposite Volta depot, NE¼ sec. 1, T. 10 S., R. 9 E. Depth, 200 feet; flows during winter months.

Location 8, sample 2790. Pacheco Pass Junction well. NE corner sec. 19, T. 10 S., R. 9 E. Depth, 150 feet.

TABLE 19.—*Quality of water in quadrangle 11, Tps. 9, 10, 11, and 12 S., Rs. 10, 11, and 12 E. (fig. 13)*

Location no.	Sample no.	Date	$K \times 10^4$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	1952	Oct. 8, 1929	109	1.13	6.40	2.45	3.05	3.23	4.04	4.63	39
2	2776	May 22, 1930	67.4	.65	4.40	1.30	.93	1.68	1.86	3.09	47
3	2777	do	30.8	.34	2.45	.35	.53	1.29	1.13	.91	27
4–S	1879	Sept. 27, 1929	6.23	.04	.40	.20	.56	.49	.38	.29	25
5	1957	Oct. 8, 1929	139	2.73	3.65	1.85	8.80	1.71	.64	11.95	84
6	2869	June 10, 1930	117	.14	1.40	8.40	.98	3.73	2.92	4.13	38
7	2867	do	71.9	.34	3.10	1.75	2.05	2.62	1.71	2.57	37
8	2778	May 23, 1930	241	2.06	3.25	8.80	11.19	3.97	3.94	15.33	66
9	2871	June 10, 1930	6305	99.00	8.95	335.50	792.88	20.79	213.85	902.69	79
10	2870	do	134	.19	2.10	8.55	1.99	4.21	4.08	4.35	34
11	2775	May 22, 1930	32.5	.16	1.30	1.30	.36	1.28	.71	.97	33
	2868	June 10, 1930	30.8	.11	1.30	1.35	.32	1.20	.77	1.00	34
12	2774	May 22, 1930	252	.18	1.40	22.25	1.93	11.46	7.94	6.18	24
13	2872	June 10, 1930	102	.14	1.05	6.15	1.13	2.24	1.91	4.18	50
14	2772	May 22, 1930	238	3.26	3.45	9.35	11.75	5.74	4.76	14.05	57
15	2771	do	167	2.50	3.10	2.75	16.68	3.79	2.98	15.78	70
16	6965	Dec. 9, 1932	303	2.40	2.35	19.50	7.84	6.23	6.14	17.32	58

DESCRIPTION OF SAMPLES OF QUADRANGLE 11 (TABLE 19 AND FIG. 13)

Location 1, sample 1952. Ben Orogen, domestic well. SE¼ sec. 15, T. 10 S. R. 10 E. Depth, 25 feet.

Location 2, sample 2776. M. B. Miranda, domestic well. Corner Fourth and P Streets, Los Banos. Depth, 33 feet.

Location 3, sample 2777. Los Banos municipal well. NW corner sec. 23, T. 10 S., R. 10 E. Depth, 122 feet; perforated below 116 feet; water stands at 10 feet.

Location 4–S, sample 1879. Santa Fe Canal at highway crossing, 3 miles east of Los Banos. San Joaquin River water diverted at Mendota.

Location 5, sample 1957. Big Water well; flowing well in slough. NW¼ sec. 27, T. 10 S., R. 11 E. Drilled to 385 feet; cased to clay at 305 feet; present discharge small.

Location 6, sample 2869. Drainage well. Near SE corner sec. 4, T. 10 S., R. 12 E. Left bank of branch of Colony Canal. Collected under direction of T. C. Mott.

Location 7, sample 2867. Drainage well, south side SW¼ sec. 2, T. 10 S., R. 12 E. North side of road at west end of Santa Rita Slough. Collected under direction of T. C. Mott.

Location 8, sample 2778. M. T. Avelar well. SW corner sec. 23, T. 11 S., R. 10 E. Depth, 235 feet; lowest water stratum, 93 feet; 8-inch discharge pipe.

Location 9, sample 2871. Miller & Lux, abandoned hole. West side of NE¼ sec. 5, T. 11 S., R. 12 E. Abandoned hole drilled to about 500 feet. Collected under direction of T. C. Mott.

Location 10, sample 2870. Drainage well. SW¼ sec. 4, T. 11 S., R. 12 E. Left bank of Laguna Canal. Collected under direction of T. C. Mott.

Location 11, samples 2775 and 2868. Drainage well. West side SE¼ sec. 2, T. 11 S., R. 12 E. Right bank of canal. Sample 2868 collected under direction of T. C. Mott.

Location 12, sample 2774. A. B. Neese well. NE¼ sec. 11, T. 11 S., R. 12 E. Depth, 12 feet.

Location 13, sample 2872. Drainage well. East side of SW¼ sec. 12, T. 11 S., R. 12 E. Right bank of Colony main canal. Collected under direction of T. C. Mott.

Location 14, sample 2772. Ora Loma Mutual well. Near NW corner sec. 23, T. 12 S., R. 11 E. New well drilled to 1,260 feet.

Location 15, sample 2771. Ora Loma Mutual well no. 24. NW¼ sec. 19, T. 12 S., R. 12 E. Depth not ascertained.

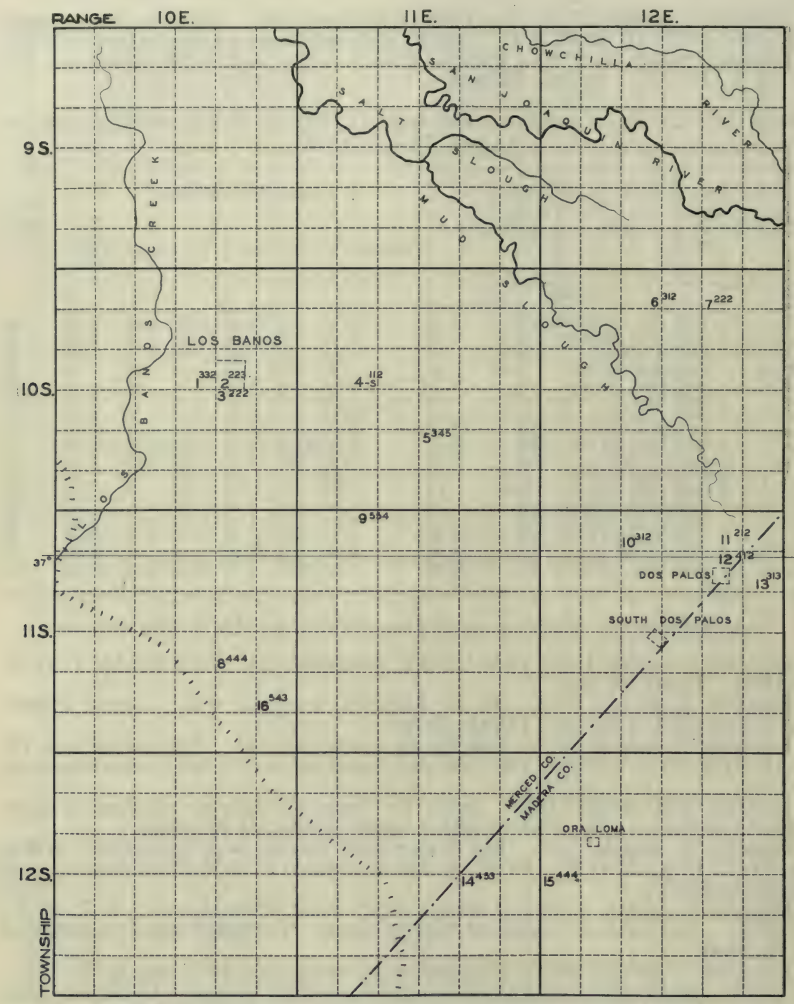

FIGURE 13.—Quadrangle 11, showing locations of samples reported in table 19.

Location 16, sample 6965. W. E. Whittington well; 7 miles south of Los Banos on Mercy Springs Road. SW¼ sec. 25, T. 11 S., R. 10 E. Depth, 608 feet; 60 feet to water; 30-foot draw-down; 12-inch casing. Collected by R. V. Wright.

TABLE 20.—*Quality of water in quadrangle 12, Tps. 9, 10, 11, and 12 S., Rs. 13, 14, and 15 E.*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	2773	May 22, 1930	71.9	0.15	1.80	4.40	0.54	2.37	0.42	3.95	59
2	3288	Sept. 17, 1930	269	.47	3.90	12.15	11 16	2.34	.65	24.22	89

DESCRIPTION OF SAMPLES OF QUADRANGLE 12 (TABLE 20)

(Quadrangle map not shown)

Location 1, sample 2773. Durham farm, flowing well. West of center of sec. 6, T. 11 S., R. 13 E. Depth could not be determined.

Location 2, sample 3288. Silaxo Station, Associated Pipe Line Co. SW¼ sec. 11, T. 12 S., R. 13 E. Depth, 465 feet; water stands at 15 feet; lower 86 feet of casing perforated.

TABLE 21.—*Quality of water in quadrangle 13, Tps. 9, 10, 11, and 12 S., Rs. 16, 17, and 18 E.*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					$CO_3 + HCO_3$	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	4531	July 7, 1931	25.1	0.05	1.95	0.55	0.07	1.25	0.66	0.72	27
2	5294	Nov. 25, 1931	29.9	.03	2.05	.70	.02	1.42	.75	.77	26
3	4530	July 7, 1931	21.0	.08	1.30	.50	.06	.79	.45	.68	35
Miscellaneous[1]	4532	do	30.1	.02	2.30	.25	.05	1.20	.96	.73	25
Do	7114	Feb. 27, 1933	28.5	.02	2.10	.48	.11	1.09	1.03	.86	35
Do	7115	do	26.8	.02	1.85	.62	.22	.99	.91	1.15	37

[1] Outside of quadrangle; included for convenience.

DESCRIPTION OF SAMPLES OF QUADRANGLE 13 (TABLE 21)

(Quadrangle map not shown)

Location 1, sample 4531. Chowchilla municipal well no. 2. Depth 104 feet; 12-inch casing, perforated below 60 feet.

Location 2, sample 5294. Stanley Yecney ranch well. Lot 7, block 7, sec. 6, T. 10 S., R. 16 E. Discharge, 0.89 cubic foot per second. Collected by E. L. Garthewaite.

Location 3, sample 4530. Madera municipal water. Sampled at tower plant. Depth of six scattered wells, 220 to 400 feet.

Miscellaneous sample 4532. Merced municipal water. From tap at Sixteenth and Main Streets.

Miscellaneous sample 7114. San Joaquin Light & Power substation well. NW¼NW¼ sec. 6, T. 8 S., R. 16 E.; 4 miles east of Athlone. Discharge, 0.04 cubic foot per second; depth, 162 feet; 12-inch casing; water clear. Collected by W. H. Alison, Jr.

Miscellaneous sample 7115. E. S. Porter well. NW¼NW¼ sec. 6, T. 8 S., R. 16 E.; 4 miles east of Athlone. One-quarter mile east of sample 7114. Depth 72 feet; water clear. Irrigation and domestic. Collected by W. H. Alison, Jr.

TABLE 22.—*Quality of water in quadrangle 14, Tps. 13, 14, 15, and 16 S., Rs. 10, 11, and 12 E. (fig. 14)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					$CO_3 + HCO_3$	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1-S	2770	May 22, 1930	659	18.60	5.45	50.95	9.46	13.89	12.00	39.97	61
2	1877	Sept. 27, 1929	130	1.97	3.20	1.80	8.65	1.35	.90	11.40	84
3	2769	May 22, 1930	418	13.10	1.75	36.80	.26	2.24	.36	36.21	93
4	2768	do	129	1.54	3.75	1.05	8.81	5.13	3.56	4.92	36
5-S	2767	do	279	4.89	5.20	4.85	22.25	7.11	9.36	15.83	49
	4833	Sept. 9, 1931	289	6.52	5.10	5.70	24.21	5.59	9.04	18.38	56
6-S	2766	May 22, 1930	806	8.78	5.70	14.90	88.82	19.51	42.37	47.54	43
	4832	Sept. 9, 1931	927	12.7	4.75	25.90	108.78	19.83	40.66	78.94	57
7	6673	Aug. 3, 1932	618	7.44	5.65	5.50	71.10	24.21	19.69	38.42	47

DESCRIPTION OF SAMPLES OF QUADRANGLE 14 (TABLE 22 AND FIG. 14)

Location 1-S, sample 2770. Little Panoche Creek. Near SE corner sec. 19, T. 13 S., R. 11 E. Flow of creek about 0.02 cubic foot per second at this point, but dry at Mercy School, above, although there were a few pools; dry or nearly so below. The bed of Salt Canyon entering just above sampling point was damp.

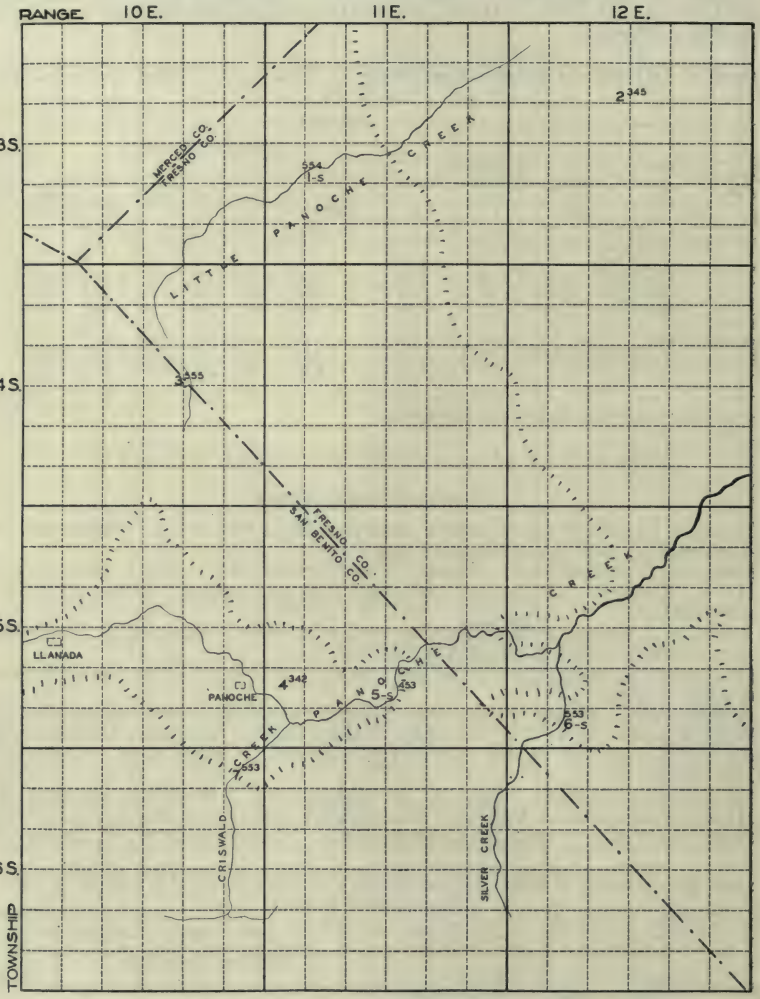

FIGURE 14.—Quadrangle 14, showing locations of samples reported in table 22.

Location 2, sample 1877. Irrigation well near SE corner sec. 9, T. 13 S., R. 12 E. Temperature, 82° F. Probably a deep well.

Location 3, sample 2769. Mercy Hot Springs. Discharge, 0.03 cubic foot per second; temperature, 120° F.

Location 4, sample 2768. Irrigation well near center sec. 30, T. 15 S., R. 11 E. Small centrifugal pump in 30-foot pit.

Location 5–S, samples 2767 and 4833. Panoche Creek. Near center W½ sec. 27, T. 15 S., R. 11 E. Discharge at time of each sample approximately 2 cubic feet per second.

Location 6–S, samples 2766 and 4832. Silver Creek. NW¼ sec. 32, T. 15 S., R 12 E. At P. G. & E. gas line crossing. Discharge at time of each sample approximately 0.03 cubic foot per second.

Location 7, sample 6673. J. H. Morgan well, domestic and irrigation. On Griswold Creek. NE¼SW¼ sec. 1, T. 16 S., R. 10 E. Dug well; depth 20 feet. Collected by R. D. McCallum.

TABLE 23.—*Quality of water in quadrangle 15, Tps. 13, 14, 15, and 16 S., Rs. 13, 14, and 15 E. (fig. 15)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	1876	Sept. 27, 1929	489	2.13	2.40	35.20	11.59	3.89	1.44	37.84	88
2	2932	June 22, 1930	203	1.20	2.95	5.50	11.46	1.17	.27	18.47	93
3	2761	May 22, 1930	329	1.06	3.33	19.70	9.02	4.04	2.00	26.01	81
4	2762	do	145	1.54	4.20	1.50	9.88	2.88	2.46	10.24	66
5-S	1949	Oct. 7, 1929	5.55	.07	.30	.05	.09	.30	.00	.14	32
6-S	1948	do	5.29	.11	.30	.15	.08	.32	.09	.12	23
7	1871	Sept. 27, 1929	166	1.23	2.40	2.30	11.40	1.01	.19	14.90	93
8	1875	do	389	1.02	2.70	26.70	9.29	4.51	3.05	31.13	80
	2760	May 22, 1930	387	.91	2.80	25.25	11.95	4.39	2.06	33.55	84
9	2763	do	146	1.58	3.85	1.30	9.13	2.68	2.05	9.55	67
10	2759	do	219	1.62	3.45	7.80	9.27	2.54	2.05	15.93	78
11	1874	Sept. 27, 1929	149	1.57	4.00	1.50	10.59	3.01	5.50	7.95	48
12	1372	June 22, 1929	580	1.47	1.75	44.50	15.18	10.80	6.41	44.22	72
13	1873	Sept. 27, 1929	189	1.39	3.20	6.20	9.33	1.59	T[1]	17.14	92
14	1872	do	155	1.23	3.00	2.50	9.97	1.53	1.48	12.46	81
15	2764	May 22, 1930	163	1.86	4.80	1.90	10.66	2.79	2.25	12.32	71
16	2765	do	154	1.43	2.80	2.50	9.33	1.16	.37	13.10	90
17-S	1947	Oct. 7, 1929	9.93	.02	.80	.10	.15	.40	.13	.52	50
18	2758	May 21, 1930	302	2.99	3.55	4.50	30.40	9.13	13.30	16.02	42
19	2757	do	127	1.18	2.70	2.00	7.69	2.48	.58	9.33	75
20	1373	June 22, 1929	140	1.88	1.39	1.39	10.90	2.02	.13	11.53	84

[1] T = trace.

DESCRIPTION OF SAMPLES OF QUADRANGLE 15 (TABLE 23 AND FIG. 15)

Location 1, sample 1876. Sellers well no. 19. S¼ corner sec. 9, T. 13 S., R. 13 E. Depth, 1,400 feet; perforated below 580 feet; discharge, 2.6 cubic feet per second; temperature, 91° F.

Location 2, sample 2932. Associated Pipe Line Co., Arbios station. NW¼ sec. 25, T. 13 S., R. 14 E. Depth, 400 feet. Reported as becoming less desirable for drinking.

Location 3, sample 2761. Irrigation well. W¼ corner sec. 31, T. 13 S., R. 14 E. Depth, 1,400 feet; stands at 165 feet.

Location 4, sample 2762. Irrigation well. SW corner SE¼ sec. 32, T. 13 S., R. 14 E. Depth, 1,400 feet; discharge, 2.9 cubic feet per second.

Location 5–S, sample 1949. San Joaquin River below Mendota Dam. This sample contains little if any storage water from Fresno Slough.

Location 6–S, sample 1948. Columbia Canal; diverted from San Joaquin above mouth of Fresno Slough.

Location 7, sample 1871. Mendota municipal well. Depth, 506 feet; lower 50 feet perforated; water stands at 67 feet. Water strata encountered after drilling through 350 or 400 feet of "blue muck", above which the water was reported to be saline.

Location 8, samples 1875 and 2760. Irrigation well. NW corner sec. 6, T. 14 S., R. 14 E. Depth, about 1,400 feet; water stands 165 feet; casing perforated at about 400 feet and below.

Location 9, sample 2763. Irrigation well. SW corner NW¼ sec. 4, T. 14 S., R. 14 E.

Location 10, sample 2759. Wayland no. 2. NW¼ sec. 7, T. 14 S., R. 14 E. Depth, 1,300 feet; stands at 180 feet; casing perforated below 400 feet; discharge, 2.7 cubic feet per second.

Location 11, sample 1874. Victoria Ranch well. SW corner sec. 8, T. 14 S., R. 14 E. Depth, 1,400 feet; stands at 167 feet.

Location 12, sample 1372. F. M. Helm, Inc., irrigation well. SW corner sec. 17, T. 14 S., R. 14 E. Depth, 1,500 feet; discharge, 2 cubic feet per second.

Location 13, sample 1873. Ensher & Alexander well no. 1. SW corner sec. 15, T. 14 S., R. 14 E. Depth, 1,250 feet; perforated below 600 feet; discharge, 2.2 cubic feet per second; temperature, 84° F.; no odor.

Location 14, sample 1872. Irrigation well. SW corner sec. 13, T. 14 S., R. 14 E.

Location 15, sample 2764. SW corner NW¼ sec. 21, T. 14 S., R. 14 E.

Location 16, sample 2765. Irrigation well. NW corner sec. 35, T. 14 S., R. 14 E. Depth, 1,400 feet.

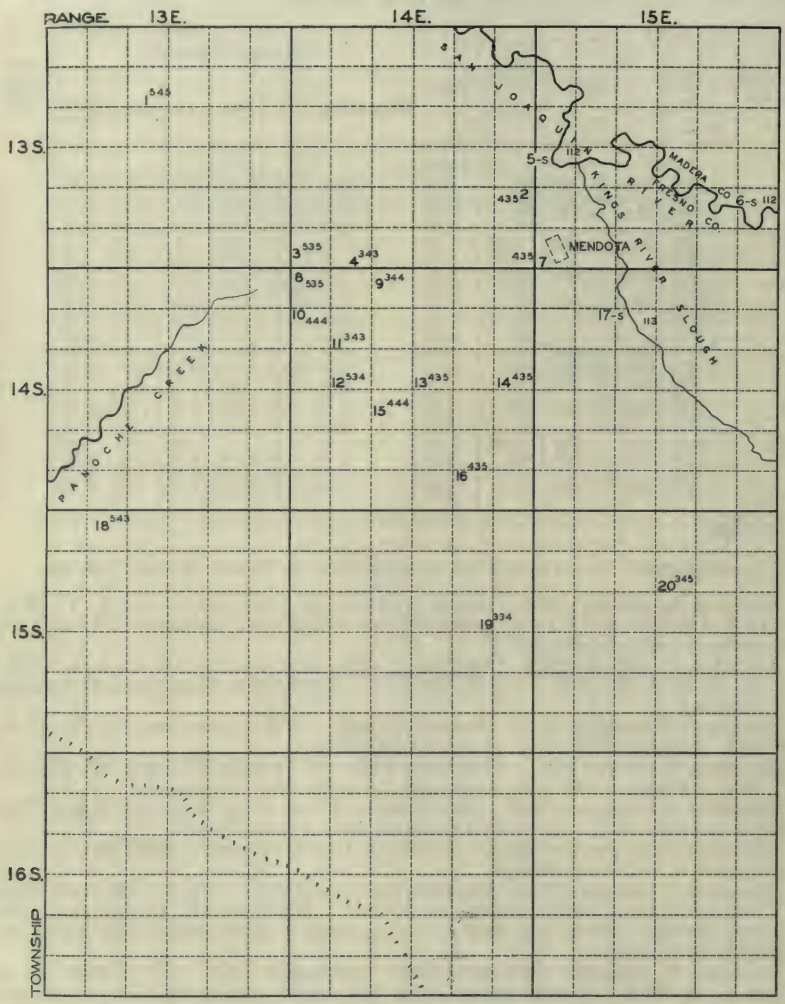

FIGURE 15.—Quadrangle 15, showing locations of samples reported in table 23.

Location 17–S, sample 1947. Kings River Slough at White's Bridge, sec. 4, T. 14 S., R. 15 E. This slough serves as a storage reservoir for San Joaquin River water before diversion at Mendota Dam.

Location 18, sample 2758. Chaney Ranch irrigation well. South center of N½ sec. 5, T. 15 S., R. 13 E. Depth, about 1,000 feet; 8-inch casing; running lift, 300 feet.

Location 19, sample 2757. Levis Pump Station, Associated Pipe Line Co. Near center east line SE¼ sec. 14, T. 15 S., R. 14 E. Depth, 1,008 feet; now stands at 94.8 feet. Reported that when drilled in 1917 the water stood 18 feet from surface.

Location 20, sample 1373. Englebreck Ranch irrigation well. Near SW corner sec. 10, T. 16 S., R. 15 E. Depth, 1,500 feet; stands at 100 feet.

TABLE 24.—*Quality of water in quadrangle 16, Tps. 13, 14, 15, and 16 S., Rs. 16, 17, and 18 E. (fig. 16)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	2931	June 22, 1930	31.5	0.09	2.30	1.00	0.05	0.34	0.11	2.90	87
2	2930	do	376	1.47	3.80	29.90	.38	2.71	.63	30.74	90
	3549	Nov. 28, 1930	281	1.08	2.55	22.05	1.15	1.90	.42	23.43	91
3	1869	Sept. 26, 1929	21.6	.04	1.60	.30	.29	1.05	.45	.69	32
4	1867	do	118	.93	1.90	1.30	7.50	1.05	.03	9.62	90
	1868	do	112	.97	2.20	1.20	6.70	1.09	T [1]	9.01	89
5	1866	do	72.4	.80	3.60	2.00	2.25	.67	.00	7.18	91
6	1865	do	125	.78	3.00	1.30	7.74	1.49	T [1]	10.55	88
7	2929	June 22, 1930	28.9	.03	2.30	.30	.28	1.19	.90	.79	27
8	3287	Sept. 17, 1930	58.5	.21	3.10	1.90	.96	1.07	.47	4.42	74
9	3286	do	88.7	1.00	5.40	2.80	.98	.68	.40	8.10	88
10	1864	Sept. 26, 1929	111	1.29	4.50	4.60	1.74	.75	.03	10.06	93

[1] T=trace.

DESCRIPTION OF SAMPLES OF QUADRANGLE 16 (TABLE 24 AND FIG. 16)

Location 1, sample 2931. Jameson, Southern Pacific Railroad section-house domestic well. Near NE corner sec. 15, T. 14 S., R. 16 E. A shallow well operated with hand pump.

Location 2, samples 2930 and 3549. Associated Pipe Line Co., Jameson station. Near NW¼ corner sec. 14, T. 14 S., R. 16 E. Depth, 600 feet; perforated from 250 feet down.

Location 3, sample 1869. Ed. Nunes service station. Probably N. line sec. 7, T. 14 S., R. 17 E. Depth, 70 feet; casing not perforated and reported to exclude three upper water-bearing strata.

Location 4, sample 1867. Tranquillity municipal well. Depth, 1,000 feet; casing not perforated; water cool.

Location 4, sample 1868. Tranquillity Creamery well. Depth, 993 feet; casing not perforated; water cool.

Location 5, sample 1866. James Irrigation District, well 29–G. Near S¼ corner sec. 22, T. 15 S., R. 16 E. Temperature, 94° F.; strong sulphur odor; formerly a flowing well.

Location 6, sample 1865. San Joaquin municipal well. Depth, 1,700 feet.

Location 7, sample 2929. James Irrigation District. Composite of discharge of the majority of a series of some 20 wells, spaced about one-third mile apart along Coalinga Road, southwest from McMullin toward Helm. Sampled from canal at SW corner sec. 30, T. 15 S., R. 18 E. Depths, 214 to 300 feet.

Location 8, sample 3287. Stinson Irrigation District. Well at SE corner sec. 10, T. 16 S., R. 17 E. Depth, 1,000 feet; perforated at all strata.

Location 9, sample 3286. Stinson Irrigation District. Well at SW corner sec. 23, T. 16 S., R. 17 E. Depth, 750 feet; 12-inch discharge pipe.

Location 10, sample 1864. Irrigation well. SW corner sec. 36, T. 16 S., R. 18 E.; 12-inch discharge pipe, flowing into open ditch.

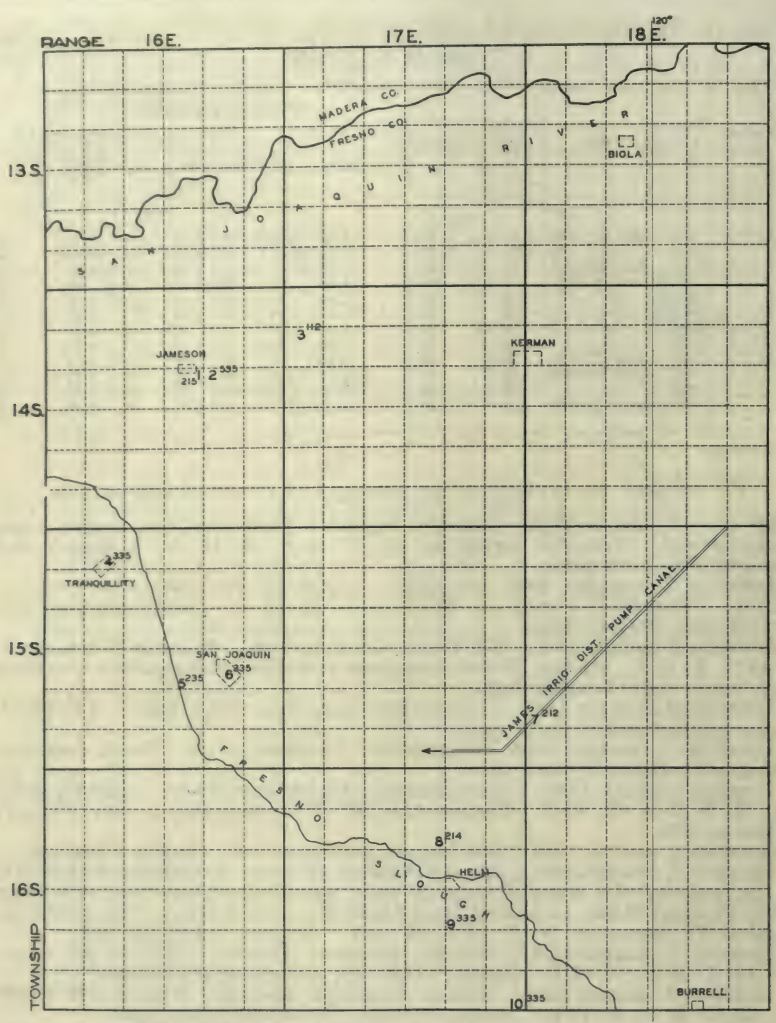

FIGURE 16.—Quadrangle 16, showing locations of samples reported in table 24.

TABLE 25.—*Quality of water in quadrangle 17, Tps. 13, 14, 15, and 16 S., Rs. 19, 20, and 21 E. (fig. 17)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Per cent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1–S	1366	June 16, 1929	5.9	0.08	0.32	0.13	0.12	0.24	T [1]	0.33	58
2	1870	Sept. 27, 1929	39.3	.01	2.50	.70	.36	1.63	1.22	.65	19
	2928	June 22, 1930	13.5	T [1]	1.10	.10	.13	.48	.55	.30	23
	4529	July 7, 1931	42.5	.04	2.85	.60	.12	1.64	1.28	1.29	31
3	5205	Nov. 14, 1931	16.7	.01	1.40	.20	.10	.59	.57	.56	33
4	2923	June 21, 1930	35.2	T [1]	2.05	.90	.18	1.80	.60	.73	23
5	4528	July 7, 1931	24.0	.08	1.45	.55	.06	1.01	.40	.78	3(
6	2922	June 21, 1930	16.0	.02	1.50	.10	.15	.76	.21	.78	46
7	2921	----do----	15.4	T [1]	1.45	.10	.13	.71	.18	.79	47

[1] T = trace.

DESCRIPTION OF SAMPLES OF QUADRANGLE 17 (TABLE 25 AND FIG. 17)

Location 1–S, sample 1366. San Joaquin River, Herndon.

Location 2, sample 1870. Fresno municipal water. Tap at E and Fresno Streets.

Location 2, sample 2928. Fresno municipal water. Tap at 1717 Del Mar Avenue.

Location 2, sample 4529. Fresno municipal water. Tap at 1202 Van Ness Street.

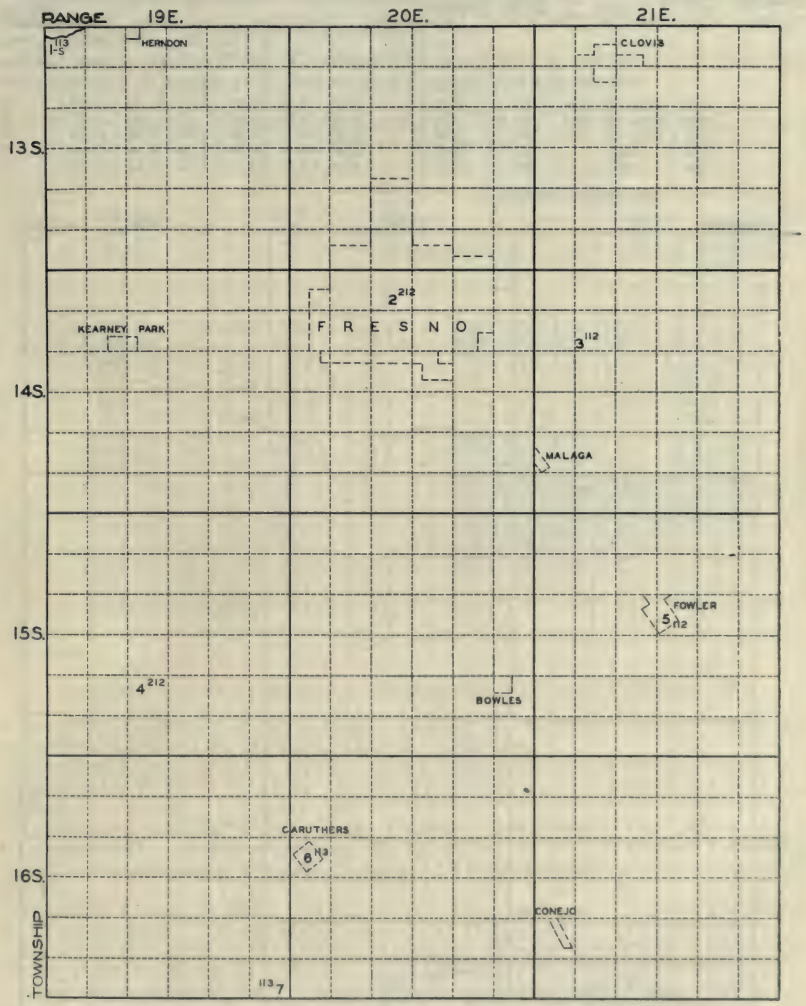

FIGURE 17.—Quadrangle 17, showing locations of samples reported in table 25.

Location 3, sample 5205. Grape experiment station well. Twenty acres at SW corner sec. 8, T. 14 S., R. 21 E. Depth, 90 feet; open bottom; 12-inch casing ending at hardpan layer at 68 feet; discharge, 0.67 cubic foot per second. Collected by E. Snyder.

Location 4, sample 2923. J. M. Long well, Raisin City. SE¼NW¼ sec. 28, T. 15 S., R. 19 E. Depth, 125 feet; water stands at 25 feet; 5-inch casing, perforated below 105 feet.

Location 5, sample 4528. Fowler municipal water. Composite of two wells; depths, 145 and 175 feet; water stands at 127 feet; casings perforated at all strata.

Location 6, sample 2922. Caruthers municipal well. Depth, 170 feet.
Location 7, sample 2921. J. T. Carreia well. SE¼ sec. 36, T. 16 S., R. 19 E. Depth, 186 feet; water stands at 20 feet.

TABLE 26.—*Quality of water in quadrangle 18, Tps. 17, 18, 19, and 20 S., Rs. 13, 14, and 15 E. (fig. 18)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Per cent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	2756	May 21, 1930	178	0.60	3.95	2.45	14.78	5.67	10.26	5.25	25
2	4848	Sept. 10, 1931	64.2	7.76	3.10	1.90	1.03	.17	.09	5.77	96
3	2755	May 21, 1930	208	1.68	5.95	3.75	13.88	2.61	9.81	11.16	47
4	2752	do	254	2.03	2.85	5.00	18.88	5.30	3.84	17.59	66
	2753	do	262	2.28	4.60	2.80	20.31	5.59	11.47	10.65	38

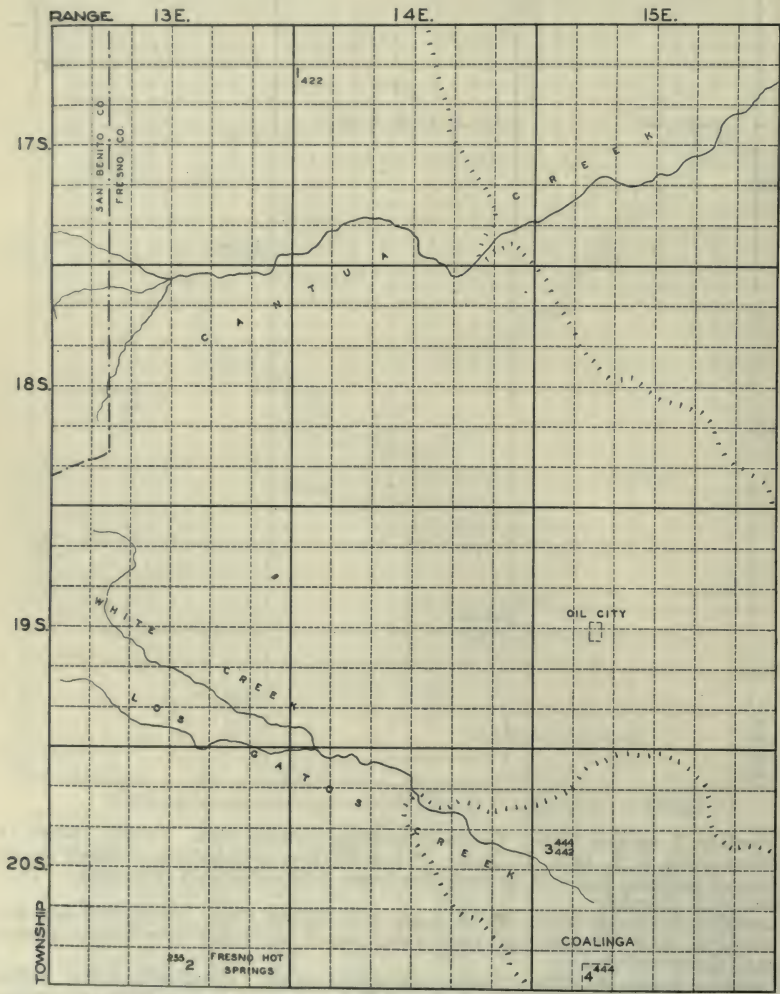

FIGURE 18.—Quadrangle 18, showing locations of samples reported in table 26.

DESCRIPTION OF SAMPLES OF QUADRANGLE 18 (TABLE 26 AND FIG. 18)

Location 1, sample 2756. Halfway Station well, Associated Pipe Line Co. Near NW corner sec. 7, T. 17 S., R. 14 E. Depth, 700 feet; 295 feet to water.

Location 2, sample 4848. Fresno (Coalinga) Hot Springs. Composite of 6 of the 15 springs at this location. Temperature, 108° F.; discharge, 0.05 cubic foot per second.

Location 3, sample 2755. Associated Oil Co., shallow domestic well. Los Gatos Creek delta; probably sec. 18, T. 20 S., R. 15 E.

Location 4, sample 2752. Coalinga municipal well no. 1. Depth, 1,410 feet; stands at 70 feet; casing perforated below 250 feet; discharge, 1.8 cubic feet per second; temperature, 91° F.

Location 4, sample 2753. Coalinga municipal well at gas plant. Depth, 1,402 feet; casing not perforated; discharge, 0.6 cubic foot per second.

TABLE 27.—*Quality of water in quadrangle 19, Tps. 17, 18, 19, and 20 S., Rs. 16, 17, and 18 E. (fig. 19)*

Location no.	Sample no.	Date	$K \times 10^3$ at 25° C.	Boron	Milligram equivalents						"Percent sodium
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	3099	July 22, 1930	92.1	1.06	1.10	0.70	6.55	1.35	0.42	6.58	79
2	3100	do	102	.62	2.20	1.00	6.34	1.99	.96	6.59	69
3	1858	Sept. 25, 1929	98.4	.95	1.10	.90	7.31	1.47	T [1]	7.84	84
4	3285	Sept. 17, 1930	60.1	.08	5.50	.50	.47	1.60	.42	4.45	69
5	1863	Sept. 26, 1929	94.8	1.30	7.10	2.60	.70	1.07	T [1]	9.33	90
6	1861	do	58.0	.89	4.60	1.50	.34	.61	0	5.83	91
7	3098	July 22, 1930	330	1.06	1.90	4.25	31.23	12.51	12.11	12.76	34
8	1857	Sept. 25, 1929	105	1.19	1.50	2.10	6.69	1.63	.93	7.73	75
9	1856	do	182	1.74	2.50	9.80	5.12	1.45	.56	15.41	87
	3097	July 22, 1930	169	1.39	2.30	8.55	5.26	1.74	.96	13.41	83
	4847	Sept. 11, 1931	176	1.62	2.40	8.60	5.82	1.47	.54	14.81	88
	4844	do	247	.99	1.90	3.40	23.58	8.16	8.44	12.56	43
10	4845	Apr. 19, 1931	193	.89	1.70	2.40	16.92	5.50	4.96	10.70	51
	4846	Sept. 11, 1931	433	1.63	2.75	8.55	41.74	12.37	16.71	27.39	49
11	3096	July 22, 1930	144	1.14	1.75	2.70	9.66	1.82	2.64	9.65	68
12	3094	do	86.6	1.01	1.80	.65	5.86	1.68	.26	6.37	77
	3095	do	87.2	.39	3.10	.65	4.62	2.57	1.26	4.54	54
13	1374	June 22, 1929	95.6	1.00	2.13	.79	6.42	1.28	T [1]	8.06	86
	1855	Sept. 25, 1929	96.3	1.10	2.10	.70	6.35	1.59	.32	7.24	79

[1] T=trace.

DESCRIPTION OF SAMPLES OF QUADRANGLE 19 (TABLE 27 AND FIG. 19)

Location 1, sample 3099. Irrigation well; T. L. Sims, tenant. Near S¼ corner sec. 14, T. 17 S., R. 16 E. Depth, 1,600 feet.

Location 2, sample 3100. Towne pump station, Standard Oil Co. Near N¼ corner sec. 8, T. 17 S., R. 17 E. Depth, 1,100 feet; water stands between 65 and 70 feet.

Location 3, sample 1858. Kings County Development Co., ranch no. 1. Irrigation well near SW corner sec. 33, T. 17 S., R. 17 E. Depth, 1,800 feet; casing perforated below 900 feet; discharge, 2.0 cubic feet per second; temperature, 86° F.

Location 4, sample 3285. W. R. Jones, irrigation well. NW¼NE¼ sec. 1, T. 17 S., R. 18 E. Depth, 80 feet; stands at 26 feet.

Location 5, sample 1863. Stinson Irrigation District well no. 7. W¼ corner sec. 9, T. 17 S., R. 18 E. Depth, about 800 feet.

Location 6, sample 1861. Tony Fatado, irrigation well. Near NE corner sec. 25, T. 17 S., R. 18 E. Depth, 408 feet; casing perforated below 150 feet.

Location 7, sample 3098. F. G. Ladd, irrigation well. NW¼ sec. 12, T. 18 S., R. 16 E. Depth, 150 feet.

Location 8, sample 1857. Kings County Development Co., ranch no. 2. Irrigation well near SW corner sec. 5, T. 18 S., R. 17 E. Depth, 1,800 feet; perforated below 900 feet; discharge, 1.8 cubic feet per second; temperature, 89° F.

Location 9, samples 1856, 3097, and 4847. Kings County Development Co., ranch no. 3. Near SW corner sec. 7, T. 18 S., R. 17 E. Depth, 1,700 feet;

perforated below 900 feet; water stands at 150 feet; discharge, 2.0 cubic feet per second; temperature, 91° F.

Location 10, sample 4844. Peter L. Ferry, irrigation well. Near center sec. 10, T. 18 S., R. 17 E. Depth, 650 feet; stands at 70 feet; draws down to 140 feet; casing perforated below 170 feet; upper 250 feet of casing 13-inch, with 10-inch casing below; discharge, 1.89 cubic feet per second. Log shows 15 sand strata alternating with clay strata.

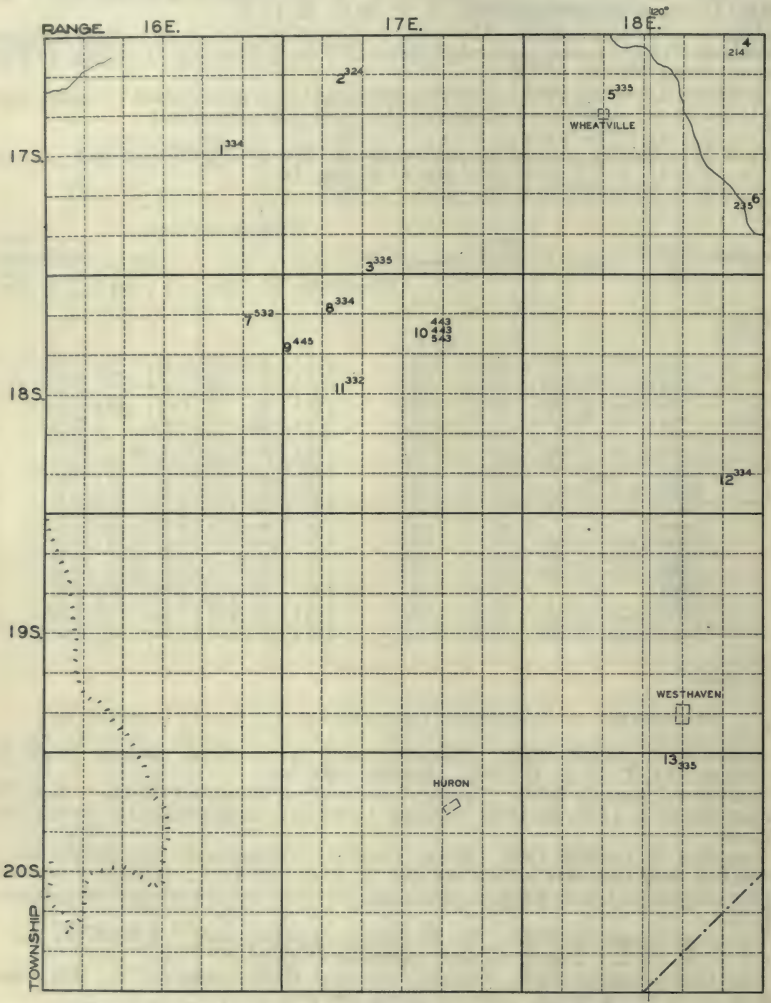

FIGURE 19.—Quadrangle 19, showing locations of samples reported in table 27.

Location 10, sample 4845. Peter L. Ferry, abandoned irrigation well. Adjacent to well represented by sample 4844. Drilled to 467 feet; perforated at 70 feet and below. Sampled in April by cooperator when pump was operating. Sample held in bottle till September.

Location 10, sample 4846. Well described under 4845. This sample represents water entering casing at 70 feet when the operation of well 4844 caused draw down in water level.

Location 11, sample 3096. Citizens National Bank of Los Angeles, irrigation well. Near SW corner of SE¼ sec. 17, T. 18 S., R. 17 E. Depth, about 1,800 feet; perforated below 900 feet.

Location 12, sample 3094. Lethant pump station, well no. 2, Standard Oil Co. Near NW corner sec. 36, T. 18 S., R. 18 E. Depth, 600 feet.

Location 12, sample 3095. Lethant station, well no. 3. Depth, 1,000 feet.

Location 13, samples 1374 and 1855. Boston Land Co., well no. 1. Near NE corner sec. 3, T. 20 S., R. 18 E. A very deep well. Log not ascertained.

TABLE 28.—*Quality of water in quadrangle 20, Tps. 17, 18, 19, and 20 S., Rs. 19, 20, and 21 E. (fig. 20)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	1862	Sept. 26, 1929	86.1	1.30	5.30	2.80	0.85	0.53	T [1]	8.42	95
2	2920	June 21, 1930	38.6	.57	3.35	1.00	.11	.22	.19	4.25	91
3	2919	do	33.0	.55	2.90	.55	.10	.28	.22	3.05	86
4-S	1377	June 22, 1929	5.4	.05	.30	.05	.06	.25	.00	.16	39
5	2918	June 21, 1930	13.5	T [1]	1.35	.10	.12	1.05	.24	.38	23
6	3075	July 22, 1930	38.0	.37	2.10	1.50	.06	.38	.21	3.07	84
7	1860	Sept. 26, 1929	27.5	.13	2.60	.20	.33	.75	T [1]	2.38	76
8	1859	do	44.8	.66	1.80	2.30	.35	.61	.00	3.84	86
9	1117	May 24, 1929	76.8	.78	4.76	2.94	.44	.44	.32	7.38	91
	1375	June 22, 1929	77.6	.67	4.64	2.88	.00	.16	T [1]	7.36	98
	1376	do	90.6	.31	7.20	1.75	.44	3.05	2.31	4.03	43
10	3074	July 21, 1930	111	1.03	3.80	.75	5.86	1.50	.44	8.47	81
11	3073	do	125	1.06	4.10	1.20	6.84	.85	.61	10.68	88
12	3072	do	109	.99	5.00	.70	5.03	.90	.40	9.43	88

[1] T=trace.

DESCRIPTION OF SAMPLES OF QUADRANGLE 20 (TABLE 28 AND FIG. 20)

Location 1, sample 1862. Henry Kapling, irrigation well. NE¼ sec. 30, T. 17 S., R. 19 E. Depth, 195 feet; casing perforated all the way down; running lift, 50 feet; 7-inch discharge pipe; water cool, but with a rather strong sulphur odor.

Location 2, sample 2920. Riverdale Cooperative Creamery Co., Riverdale. NW¼ sec. 25, T. 17 S., R. 19 E. Depth, 210 feet; casing not perforated.

Location 3, sample 2919. G. G. Rogers, domestic well. Near NW corner sec. 30, T. 17 S., R. 20 E. Depth, 200 feet; static level, 28 feet.

Location 4–S, sample 1377. Irrigation canal from Kings River. Lemoore-Hanford highway.

Location 5, sample 2918. Lucern Vineyard. Near center sec. 10, T. 18 S., R. 21 E. Depth, 120 feet; static level, 15 feet; discharge, 3.2 cubic feet per second.

Location 6, sample 3075. Hanford municipal. California Water Service Corporation, station no. 3 well, West Florinda Street and Hanford Avenue. Depth, 1,100 feet; casing perforated below 600 feet.

Location 7, sample 1860. Hanford municipal. California Water Service Corporation, station no. 2 well, Harris and Water Streets. Depth, 1,500 feet; casing perforated below 600 feet; static level, 38 feet; draws down to about 60 feet.

Location 8, sample 1859. Hanford municipal. California Water Service Corporation, station no. 1 well, 131 West Fifth Street. Depth, 900 feet; casing perforated below 600 feet; static level, 45 feet; draws down to about 60 feet.

Location 9, samples 1117 and 1375. Lemoore municipal. A deep well. Sample 1117 collected by F. E. Smith.

Location 9, sample 1376. Lemoore. A shallow well at old high school.

Location 10, sample 3074. A. E. Blakeley, irrigation well. NE¼ sec. 13, T. 20 S., R. 19 E. Depth, 860 feet; draws down to 91 feet; casing perforated below 400 feet.

Location 11, sample 3073. Stratford municipal water. Well one-half mile west of town. Depth, about 1,100 feet.

Location 12, sample 3072. C. H. Meyer, irrigation well. Near NE corner sec. 29, T. 20 S., R. 20 E. Depth, 1,095 feet; temperature, 81° F.

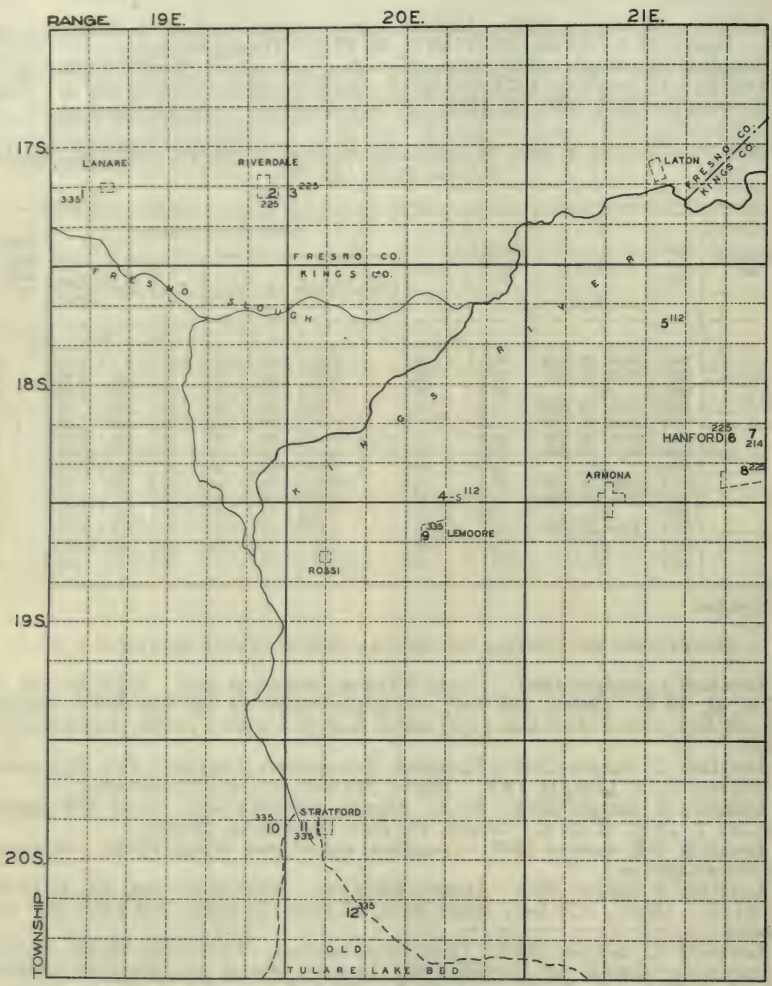

FIGURE 20.—Quadrangle 20, showing locations of samples reported in table 28.

TABLE 29.—*Quality of water in quadrangle 21, Tps. 17, 18, 19, and 20 S., Rs. 22, 23, and 24 E. (fig. 21)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	1365	June 16, 1929	7.2	0.03	0.47	0.05	0.14	0.33	0.03	0.30	45
	1946	Oct. 6, 1929	14.8	T [1]	1.10	.15	.18	.68	.09	.66	46
2	3076	July 22, 1930	23.8	.14	1.95	.30	.06	.20	.32	1.79	77
3	4526	July 7, 1931	20.1	.12	1.38	.20	.02	.82	.16	.58	37
4	2916	June 21, 1930	35.1	.29	2.80	1.30	.21	.33	.11	3.87	90
5	2912	do	19.2	.18	1.80	.20	.15	.49	.14	1.52	71
6	2917	do	211	.48	10.00	9.25	2.69	4.19	2.04	15.71	72
7	4525	July 7, 1931	16.9	.04	1.60	.15	.07	.33	.07	1.46	78
Miscellaneous [2]	3048	July 11, 1930	61.1	.10	4.30	1.25	.67	3.03	2.33	.86	14

[1] T=trace.

[2] Outside of quadrangle; included for canvenience.

DESCRIPTION OF SAMPLES OF QUADRANGLE 21 (TABLE 29 AND FIG. 21)

Location 1–S, samples 1365 and 1946. Kings River, between Traver and Kingsburg. (See also sample 1377, location 4, quadrangle 20.)

Location 2, sample 3076. Hanford municipal, California Water Service Corporation, station no. 4 well. East County Road at Eleventh Street. Depth, 500 feet; casing perforated below 200 feet.

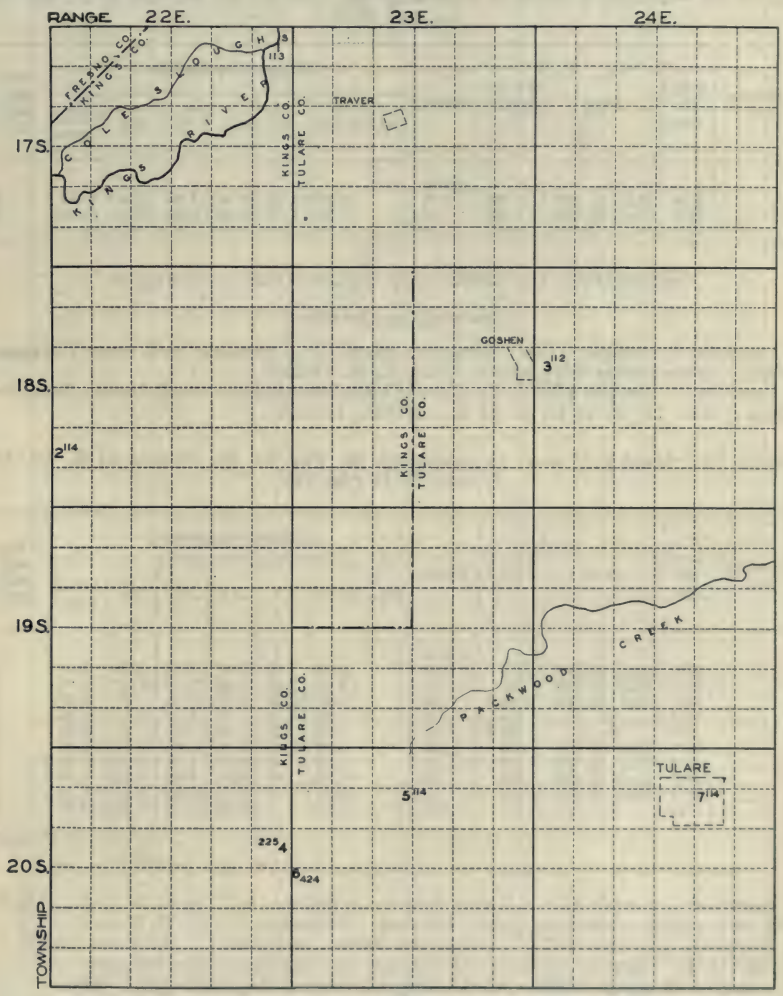

FIGURE 21.—Quadrangle 21, showing locations of samples reported in table 29.

Location 3, sample 4526. Goshen Junction. Southern Pacific depot well. Depth, about 300 feet.

Location 4, sample 2916. C. V. Wreden, irrigation well no. 1. SE¼ sec. 13, T. 20 S., R. 22 E. Depth, 2,100 feet; casing perforated from 600 feet down.

Location 5, sample 2912. Tagus Ranch, James Thomas, irrigation well. Near NE corner sec. 9, T. 20 S., R. 23 E. Depth, 563 feet.

Location 6, sample 2917. C. V. Wreden. NW¼ sec. 19, T. 20 S., R. 23 E. Depth, about 100 feet.

Location 7, sample 4525. Tulare municipal well. Composite of two wells at O Street plant. Depths, 669 and 770 feet; casings perforated below 300 feet; combined discharges, 5.6 cubic feet per second.

Miscellaneous sample 3048. Minnehaha Orchards. Approximately 5 miles northwest of Woodlake. Composite sample of battery of 19 wells. Collected by E. R. Parker.

TABLE 30.—*Quality of water in quadrangle 22, Tps. 21, 22, 23, and 24 S., Rs. 13, 14, and 15 E.*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	2754	May 21, 1930	506	4.29	6.20	14.20	41.36	13.33	7.25	41.18	66
2	2751	May 20, 1930	278	.80	2.90	5.10	24.85	8.33	9.54	14.98	46

DESCRIPTION OF SAMPLES OF QUADRANGLE 22 (TABLE 30)

(Quadrangle map not shown)

Location 1, sample 2754. Crescent Meat Co. Shallow well near Waltham Creek. Near center W½ sec. 8, T. 21 S., R. 15 E.

Location 2, sample 2751. T. Curvi. Shallow domestic well beside Jacalitos Creek. Sec. 14, T. 21 S., R. 15 E. Depth, 15 feet.

TABLE 31.—*Quality of water in quadrangle 23, Tps. 21, 22, 23, and 24 S., Rs. 16, 17, and 18 E. (fig. 22)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	3210	Aug. 22, 1930	154	0.50	2.30	1.90	12.87	5.84	5.34	5.89	35
2	2877	June 12, 1930	165	.52	2.45	1.80	13.66	6.07	6.00	5.84	33
3	1854	Sept. 25, 1929	93.3	.38	1.50	1.20	6.34	2.19	.38	6.47	72
4	1852	-----do-----	100	.38	1.40	1.10	7.22	2.89	1.15	5.68	58
5	1853	-----do-----	98.5	.40	1.50	1.20	6.86	2.55	.87	6.14	64
6	2876	June 19, 1930	359	.23	5.00	1.65	42.46	21.85	17.71	9.55	19
7	2750	May 20, 1930	235	.66	6.80	1.40	19.75	7.95	8.70	11.30	40
8	2875	June 12, 1930	169	.25	4.15	.60	14.83	5.45	7.32	6.81	35
9	2749	May 20, 1930	200	.32	1.90	1.20	18.23	6.06	8.15	7.12	33
10	2748	-----do-----	296	1.28	2.05	6.05	23.40	9.16	7.47	14.87	47

DESCRIPTION OF SAMPLES OF QUADRANGLE 23 (TABLE 31 AND FIG. 22)

Location 1, sample 3210. Hayes Ranch. SW¼ sec. 1, T. 21 S., R. 16 E. Depth 165 feet; casing perforated below 105 feet. Collected by W. T. Hayes.

Location 2, sample 2877. Talvodero Ranch, stock well. NE¼ sec. 22, T. 21 S., R. 16 E. Depth, 100 feet. Collected by Theodore Kreyenhagen.

Location 3, sample 1854. G. M. Gifford & Sons, irrigation well. About 1,500 feet north of SW corner sec. 14, T. 21 S., R. 18 E. Depth, 1,000 feet; casing perforated below 500 feet; static level, 112 feet; discharge, 1 cubic foot per second; cool.

Location 4, sample 1852. Kings County Packing Co. well. Near NW corner sec. 15, T. 21 S., R. 18 E. Depth,1,700 feet; discharge, 1.8 cubic feet per second.

Location 5, sample 1853. Kings County Packing Co. N¼ corner sec. 23, T. 21 S., R. 18 E. Depth, 1,400 feet; casing perforated below 500 feet; temperature, 82° F.

Location 6, sample 2876. Well near Zapata Creek, drilled to supply rotary oil rig. NE¼ sec. 18, T. 22 S., R. 16 E. Depth, 512 feet. Collected by Theodore Kreyenhagen.

Location 7, sample 2750. Theodore Kreyenhagen, domestic well. Near center sec. 9, T. 22 S., R. 16 E. Depth, 20 feet.

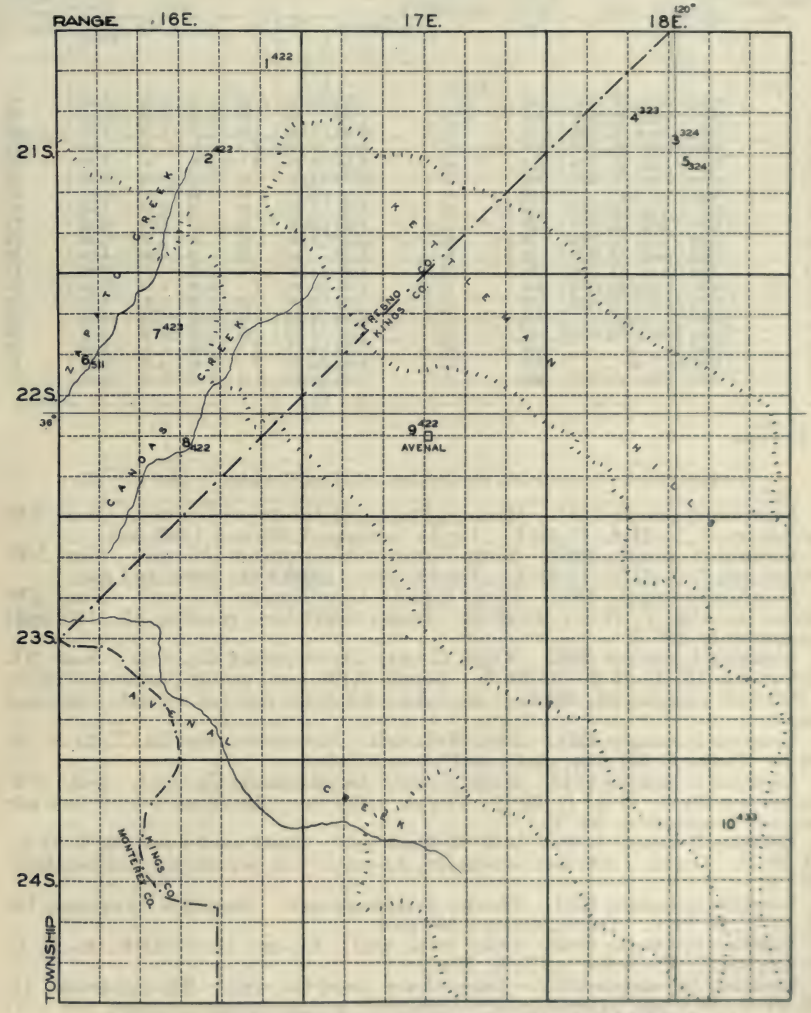

FIGURE 22.—Quadrangle 23, showing locations of samples reported in table 31.

Location 8, sample 2875. Stock well near Canoas Creek. NW¼ sec. 27, T. 22 S., R. 16 E. Depth, 100 feet. Collected by Theodore Kreyenhagen.

Location 9, sample 2749. Avenal. Collected from tap supplied by a well 500 feet deep in sec. 21, T. 22 S., R. 17 E.

Location 10, sample 2748. Dudley pump station, Union Oil Co. Piped from wells several miles away, presumably in sec. 11, T. 24 S., R. 18 E. Well in operation; reported to be 119 feet deep with static level of 32 feet.

TABLE 32.—*Quality of water in quadrangle 24, Tps. 21, 22, 23, and 24 S., Rs. 19, 20, and 21 E. (fig. 23)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	1851	Sept. 25, 1929	145	(1)	7.30	7.00	0.40	1.15	1.60	11.95	81
2	3093	July 22, 1930	155	0.79	7.40	7.55	.40	1.58	1.16	12.61	82
3	1850	Sept. 25, 1929	171	.87	10.60	7.60	.09	1.77	1.20	15.32	84
4	3092	July 22, 1930	137	.47	6.30	7.35	T [2]	1.54	1.03	11.08	81
5	3071	July 21, 1930	112	.40	5.30	5.40	T [2]	1.28	.81	8.61	80
6	1849	Sept. 25, 1929	243	.91	10.00	14.60	.15	2.31	1.28	21.16	85
7	1848	do	124	.46	5.60	6.70	.02	1.43	.48	10.41	85
8	3251	Aug. 29, 1930	49.3	.22	3.95	1.00	.21	.76	2.96	1.44	28
9	3162	Aug. 15, 1930	126	.52	7.20	5.25	.14	1.57	1.60	9.42	75
10	3252	Aug. 29, 1930	73.9	.65	3.10	4.20	.05	.90	1.02	5.43	74
11	1845	Sept. 25, 1929	62.3	.48	6.40	.50	.05	1.23	.96	4.76	68
12	3163	Aug. 15, 1930	94.0	.30	4.65	4.60	.01	1.26	.51	7.49	81
13	3091	July 22, 1930	348	.37	6.95	25.90	T [2]	4.56	6.78	21.51	65
14	1846	Sept. 25, 1929	108	.49	4.60	5.90	.06	1.27	.32	8.97	85
15	1847	do	144	.27	6.90	7.30	.05	2.49	1.20	10.56	74
	3169	July 22, 1930	145	.25	7.00	7.10	.04	2.38	2.19	9.57	68
16	3090	do	109	.20	5.80	4.75	T [2]	2.00	1.45	7.10	67
17	3089	do	220	.26	8.30	12.80	T [2]	3.49	4.34	13.27	63
18	3070	July 21, 1930	524	2.29	37.00	22.15	2.14	5.90	13.30	42.09	69

[1] Lost.
[2] T = trace.

DESCRIPTION OF SAMPLES OF QUADRANGLE 24 (TABLE 32 AND FIG. 23)

Location 1, sample 1851. Missouri State Life Insurance Co. well. Near NW corner sec. 1, T. 21 S., R. 19 E. Depth, between 1,700 and 1,800 feet.

Location 2, sample 3093. Kings County Development Co. well. Near NW corner sec. 7, T. 21 S., R. 20 E. Depth, about 1,800 feet; warm and gas.

Location 3, sample 1850. Kings County Development Co. well. Near NW corner sec. 18, T. 21 S., R. 20 E. Depth 1,800 feet; running lift, 160 feet; temperature, 90° F.

Location 4, sample 3092. Kings County Development Co. well. Near NE corner sec. 18, T. 21 S., R. 20 E. Depth, 2,100 feet; casing perforated below 1,200 feet; running lift, 200 feet; discharge, 4.5 cubic feet per second; warm and gas.

Location 5, sample 3071. Nick Weis well. Near center sec. 23, T. 21 S., R. 20 E. Depth, 1,951 feet; perforated below 955 feet.

Location 6, sample 1849. Kings County Development Co. well. Near NW corner sec. 30, T. 21 S., R. 20 E. Depth, 1,950 feet; discharge, 4 cubic feet per second; temperature, 99° F.

Location 7, sample 1848. A. H. Wolfsen well. North center sec. 36, T. 21 S., R. 20 E. Depth, 1,800 feet; discharge, 3.6 cubic feet per second; temperature, 91° F.

Location 8, sample 3251. Charles Slaybaugh well. Near E¼ corner sec. 12, T. 21 S., R. 21 E. Depth, about 1,500 feet.

Location 9, sample 3162. Gilky Bros. well. E½ sec. 19, T. 21 S., R. 21 E. A deep well. Collected by H. E. Hite.

Location 10, sample 3252. Tulare Lake Land Co. well. N¼ corner sec. 22, T. 21 S., R. 21 E. Depth, about 1,800 feet; casing perforated below 850 feet; temperature not high; considerable gas.

Location 11, sample 1845. Frank Helm well. Near NE corner sec. 24, T. 21 S., R. 21 E. Depth, 1,425 feet; water stands at about 50 feet.

Location 12, sample 3163. W. A. Crockett well. E½ sec. 33, T. 21 S., R. 21 E. A deep well. Collected by H. E. Hite.

Location 13, sample 3091. Kings County Development Co. well. Near SE corner sec. 5, T. 22 S., R. 21 E. Depth 2,100 feet; casing perforated below 1,400 feet; discharge, 4.5 cubic feet per second; running lift, 200 feet. Water warm; gas present.

Location 14, sample 1846. El Rico Land Co. well. Near SE corner NE¼ sec. 1, T. 22 S., R. 21 E. Depth, 1,800 feet; temperature, 90° F.; considerable gas.

Location 15, samples 1847 and 3169. Kings County Development Co. well. SE corner sec. 8, T. 22 S., R. 21 E. Depth, 1,970 feet; temperature, 93° F.; casing perforated below 1,400 feet; discharge, 3.3 cubic feet per second. Well produces considerable gas; when ignited a flame several feet high burns above discharge pipe.

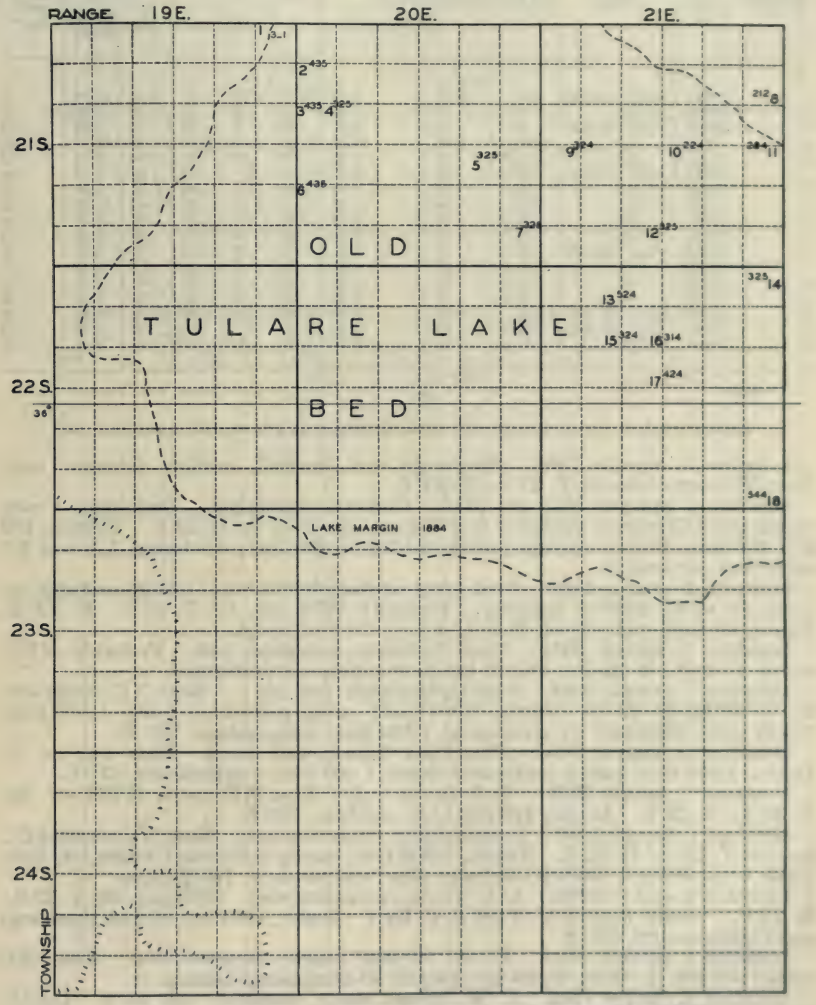

FIGURE 23.—Quadrangle 24, showing locations of samples reported in table 32.

Location 16, sample 3090. Kings County Development Co. well. Near SE corner sec. 9, T. 22 S., R. 21 E. Depth, 1,970 feet; casing perforated below 1,400 feet; static level, 75 feet; running lift, 160 feet; temperature, 91° F.

Location 17, sample 3089. Kings County Development Co. well. Near SE corner sec. 16, T. 22 S., R. 21 E. Depth, 1,800 feet; running lift, 185 feet; discharge, 3.7 cubic feet per second; warm water and considerable gas.

Location 18, sample 3070. Gates Ranch, shallow well. Near SE corner sec. 36, T. 22 S., R. 21 E. Depth, about 150 feet; water used only for washing, etc. Gas from the well is trapped and used for gas ranges.

TABLE 33.—*Quality of water in quadrangle 25, Tps. 21, 22, 23, and 24 S., Rs. 22, 23, and 24 E. (fig. 24)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Per cent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	1844	Sept. 24, 1929	134	0.86	9.50	2.00	2.93	1.67	0.40	12.36	86
2	1843	do	18.2	.15	1.50	.20	.13	.61	.00	1.22	67
	2915	June 21, 1930	19.6	.11	2.00	.20	.11	.52	.12	1.68	72
3	2914	do	492	1.98	36.90	17.00	2.78	2.39	2.18	52.11	92
4	2913	do	18.3	.03	1.50	.15	.31	.71	.14	1.11	57
5	3068	July 21, 1930	92.4	.49	4.40	4.55	T [1]	.97	.56	7.42	83
	3069	do	92.6	.27	5.80	3.40	T [1]	1.36	1.54	6.30	68
6	3066	do	164	.90	11.70	4.10	2.17	1.87	1.80	14.30	80
7	3067	do	72.2	.37	6.35	1.20	T [1]	1.30	.98	5.27	70
	3065	do	42.3	.19	3.90	.45	.20	.74	.55	3.26	72
9	1841	Sept. 24, 1929	34.9	.11	1.80	.90	.63	1.03	.71	1.59	48
	1842	do	20.0	.07	1.60	.20	.17	.45	T [1]	1.52	77
10	1839	do	23.6	.09	1.50	.50	.41	.49	.00	1.92	80
11	1840	do	34.4	.15	2.40	.90	.14	.59	.51	2.34	68
12	3284	Sept. 16, 1930	1,055	5.97	28.10	85.00	.29	3.65	12.90	96.84	85
13	5946	Apr. 19, 1932	82.8	.58	5.40	2.95	T [1]	.63	.68	7.04	84
14	5945	do	69.3	.43	5.80	1.35	.01	1.47	.94	4.75	66

[1] T=trace.

DESCRIPTIONS OF SAMPLES OF QUADRANGLE 25 (TABLE 33 AND FIG. 24)

Location 1, sample 1844. Slaybaugh and Boswell, shallow domestic well. Near W¼ corner sec. 6, T. 21 S., R. 21 E.

Location 2, samples 1843 and 2915. Corcoran municipal. Two wells, 1 mile northeast of Corcoran, probably in SW¼ sec. 12, T. 21 S., R. 22 E. Depths, 400 and 460 feet, 12-inch casings perforated below 200 feet; discharge, 1.8 and 2.0 cubic feet per second.

Location 3, sample 2914. Fred Long service station well, 1 mile west of Corcoran on south side of highway. Probably SW¼ sec. 15, T. 21 S., R. 22 E. Depth, 60 feet; static level, 26 feet; 4-inch discharge pipe.

Location 4, sample 2913. Cord Uptbrove, irrigation well. Probably NW¼ sec. 5, T. 21 S., R. 23 E. Depth 198 feet; casing not perforated.

Location 5, sample 3068. Post Card Ranch, well no. 1. Near NE corner sec. 21, T. 22 S., R. 22 E. Depth, 2,300 feet; casing perforated below 1,500 feet; report water produced by stratum at 1,800 feet; temperature, 90° F.

Location 5, sample 3069. Post Card Ranch, well no. 4. Near well no. 1. Depth, 1,900 feet; casing perforated below 1,400 feet; temperature, 83° F.

Location 6, sample 3066. W. J. Smith well. Near NE corner NW¼ sec. 24, T. 22 S , R. 22 E. Depth, 470 feet; temperature, 70° F.

Location 7, sample 3067. Forrest Riley, irrigation well. Near NE corner SE¼ sec. 24, T. 22 S., R. 22 E. Depth, 2,000 feet; casing perforated below 900 feet; static level, 90 feet; 10-inch discharge pipe; temperature, 78° F.; gas.

Location 8, sample 3065. A. V. Taylor, irrigation well. NE¼ sec. 20, T. 22 S., R. 23 E. (1 mile west of A., T., & S. F. Ry.) Depth, 460 feet; 10-inch discharge pipe; temperature, 69° F.

Location 9, sample 1841. C. W. Bryson ranch, domestic well. Near NE corner sec. 28, T. 22 S., R. 23 E. Depth, 75 feet; 2-inch casing.

Location 9, sample 1842. C. W. Bryson ranch, irrigation well no. 4. Depth, between 350 and 400 feet; 7-inch discharge pipe.

Location 10, sample 1839. Alpaugh Irrigation District canal. Sampled in sec. 33, T. 23 S., R. 23 E. The sample represents water principally if not entirely from a group of 21 wells located near Smyrna. These wells are reported to vary in depth from "shallow" to 1,000 feet. Analysis reported also under quadrangle 28.

Location 11, sample 1840. Alpaugh municipal water, from several wells 1 to 3 miles west of Alpaugh. Depth reported to be about 1,000 feet.

Location 12, sample 3284. Deep well west of La Hacienda Ranch. SW¼ sec. 19, T. 24 S., R. 22 E. Depth, 835 feet; static level, 12 feet; 12-inch casing;

perforations thought by stockman to be below 500 feet; operated by small rotary pump to supply cattle; drilled in 1929.

Location 13, sample 5946. La Hacienda Ranch, well, headquarters. Near center sec. 17, T. 24 S., R. 22 E. Depth, 830 feet; upper perforations at 400 feet;

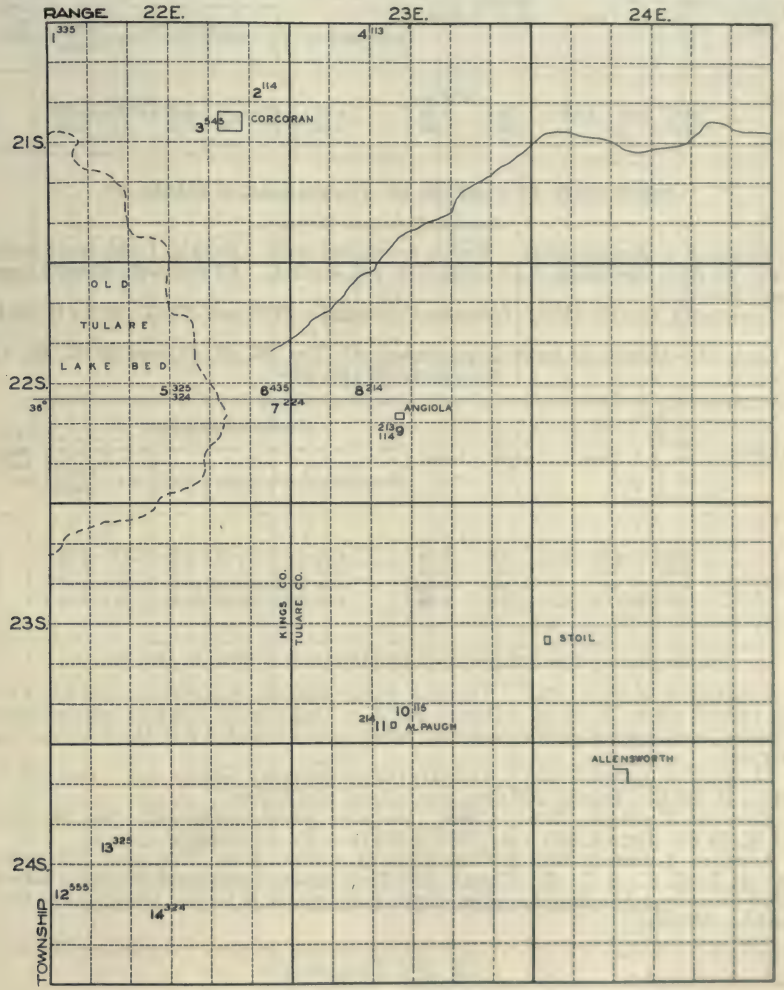

FIGURE 24.—Quadrangle 25, showing locations of samples reported in table 33.

9⅝-inch casing. Used for stock and domestic purposes. Collected by Roy Filcher.

Location 14, sample 5945. La Hacienda Ranch, well no. 7. NE¼ sec. 28, T. 24 S., R. 22 E. Depth, 990 feet; upper perforations at about 400 feet; 14-inch casing to 150 feet, then 12-inch; discharge, 2 cubic feet per second. Collected by Roy Filcher.

TABLE 34.—*Quality of water in quadrangle 26, Tps. 21, 22, 23, and 24 S., Rs. 25, 26, and 27 E.*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	4524	July 7, 1931	20.1	0.09	1.65	0.20	0.07	0.06	0.06	1.80	94
2	4523	do	36.1	.05	2.20	.45	.34	1.35	.48	1.70	48

DESCRIPTION OF SAMPLES OF QUADRANGLE 26 (TABLE 34)

(Quadrangle map not shown)

Location 1, sample 4524. Pixley municipal well. Depth, 1,180 feet; static level, 64 feet; discharge, 0.12 cubic foot per second. An old well which at one time flowed.

Location 2, sample 4523. Jorgensen vineyard. SE¼ sec. 34, T. 24 S., R. 25 E.

TABLE 35.—*Quality of water in quadrangle 27, Tps. 25, 26, 27, and 28 S., Rs. 19, 20, and 21 E. (fig. 25)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	2747	May 20, 1930	458	3.94	4.85	13.05	35.22	8.36	18.42	26.34	50
2	2746	do	363	1.15	3.35	17.10	18.40	9.93	9.35	19.57	50
3	2745	do	545	3.31	3.05	21.60	36.96	14.07	13.67	33.87	55
4	3281	Sept. 16, 1930	610	5.23	1.40	15.30	59.38	24.30	7.24	44.55	59

DESCRIPTION OF SAMPLES OF QUADRANGLE 27 (TABLE 35 AND FIG. 25)

Location 1, sample 2747. Temblor pump station, Associated Pipe Line Co. Sec. 20, T. 25 S., R. 19 E. Depth, 501 feet; static level, 120 feet; report water stratum encountered at 300 feet with other strata about 3 feet thick to shale at 500 feet.

Location 2, sample 2746. S. & G. Gump property, sheep well. Sec. 25, T. 26 S., R. 19 E. Depth, 363 feet; static level at 357 feet.

Location 3, sample 2745. Chris. Trisslman ranch, sheep well. Sec. 9, T. 27 S., R. 20 E. Depth, 500 feet; "lift", 260 feet; 2½-inch casing.

Location 4, sample 3281. State highway station, Lost Hills, near NE corner sec. 3, T. 27 S., R. 21 E. Depth, 300 feet; casing perforated for three strata. Well runs dry a few minutes after starting and water is hauled both for the lawn and for drinking.

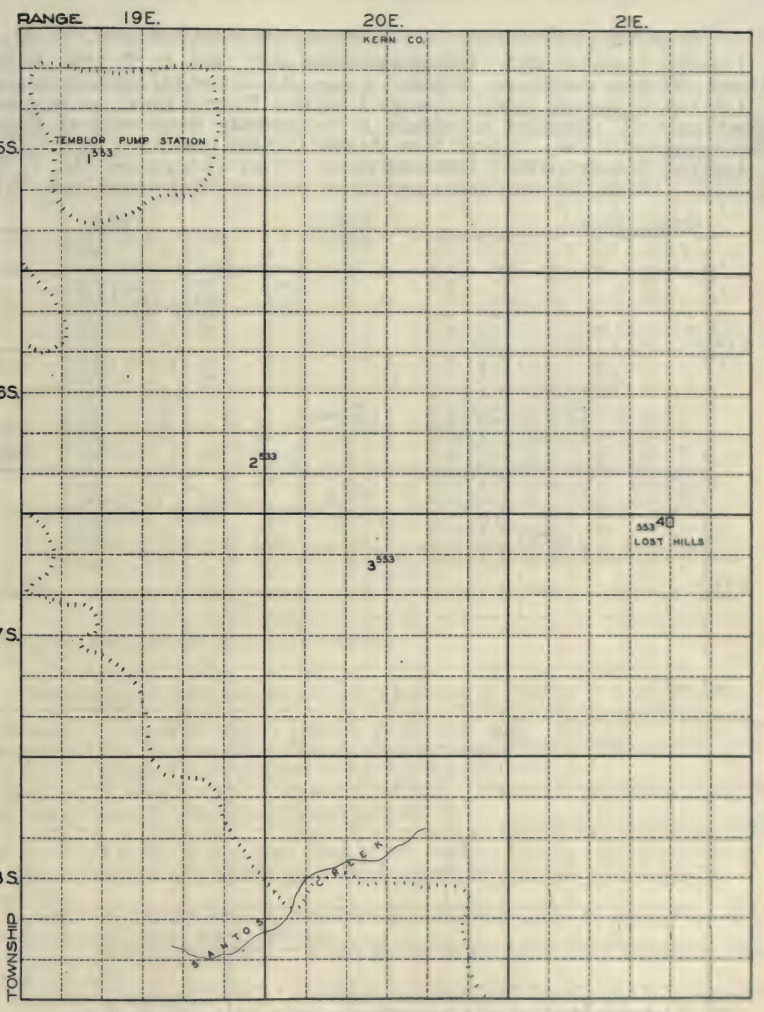

FIGURE 25.—Quadrangle 27, showing locations of samples reported in table 35.

TABLE 36.—*Quality of water in quadrangle 28, Tps. 25, 26, 27, and 28 S., Rs. 22, 23, and 24 E. (fig. 26)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	3283	Sept. 16, 1930	19.7	0.14	1.90	0.20	0.14	0.27	0.28	1.69	75
2	1839	Sept. 24, 1929	23.6	.09	1.50	.50	.41	.49	.00	1.92	80
3	3282	Sept. 16, 1930	49.8	.32	1.80	1.65	1.49	.25	.33	4.36	88
4	3280	....do....	133	.40	1.70	10.30	T [1]	1.76	.28	9.96	83
5	2744	May 20, 1930	20.8	.10	1.90	.40	.26	.40	.19	1.97	77
6	4831	Sept. 7, 1931	155	.34	1.30	7.20	0.77	7.32	.20	7.82	51

[1] T=trace.

DESCRIPTION OF SAMPLES OF QUADRANGLE 28 (TABLE 36 AND FIG. 26)

Location 1, sample 3283. Old Fowler ranch well. Sec. 10, T. 25 S., R. 22 E. Depth, 700 feet; static level, 18 feet. A very old well which formerly flowed.

Location 2, sample 1839. Alpaugh Irrigation District canal, as sampled in quadrangle 25. Supplied principally if not entirely from wells at Smyrna. Wells reported to vary in depth from shallow to 1,000 feet.

Location 3, sample 3282. Gilbreath ranch. Near SE corner sec. 10, T. 26 S., R. 22 E. Depth, 800 feet; casing perforated below 600 feet; static level, 18 feet.

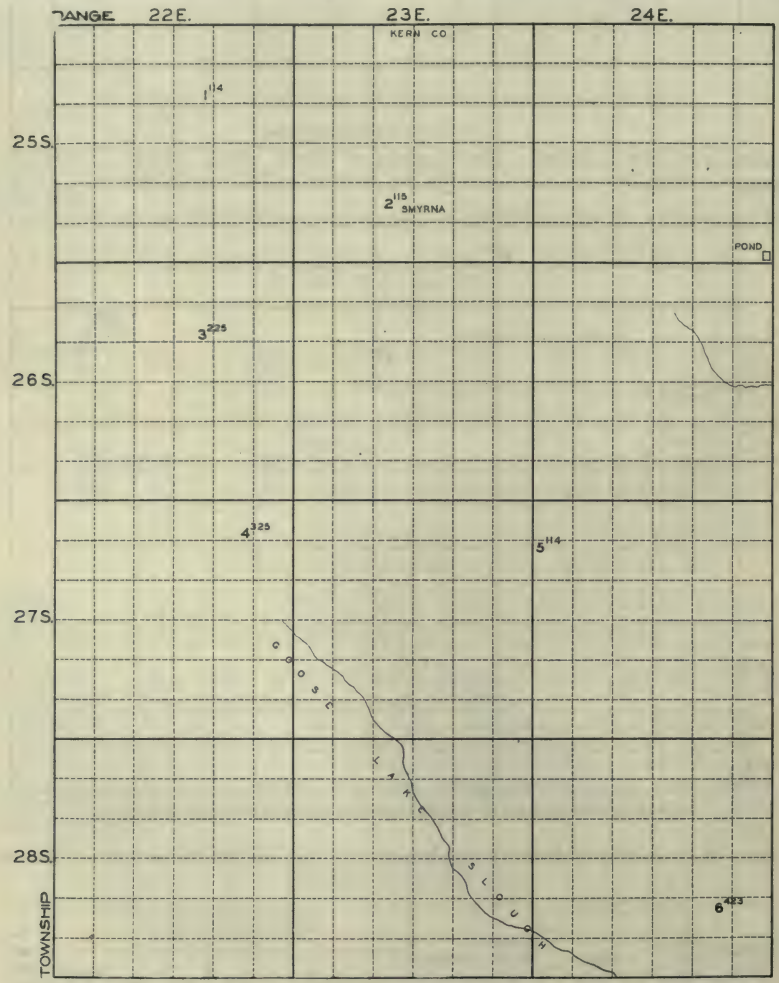

FIGURE 26.—Quadrangle 28, showing locations of samples reported in table 36.

Location 4, sample 3280. E. A. Meyer chicken ranch well. Near SE corner sec. 2, T. 27 S., R. 22 E. Depth, 170 feet; casing not perforated; static level, 50 feet.

Location 5, sample 2744. Semitropic wells supplying General Petroleum pump station at Belridge. Depth not ascertained.

Location 6, sample 4831. C. P. Morgan, irrigation well. Sec. 26, T. 28 S., R. 24 E. Depth, 112 feet; casing perforated at several strata. Reported that the domestic well of similar depth but with an unperforated casing produced a softer water. The boron symptoms were pronounced on dooryard plants irrigated from the domestic well.

TABLE 37.—*Quality of water in quadrangle 29, Tps. 25, 26, 27, and 28 S., Rs. 25 26, and 27 E. (fig. 27)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	4522	July 7, 1931	41.5	0.03	1.90	0.80	1.05	1.53	0.98	1.60	39
2	4520	do	19.2	.03	1.70	.15	.12	.86	.10	1.05	52
3	624	Feb. 5, 1929	49.5	.14	3.50	.30	.69	2.83	1.13	.53	12
4	4521	July 7, 1931	25.4	.01	2.15	.10	.43	1.42	.47	.85	31
5-S	2911	June 21, 1930	7.71	.03	.70	.10	.31	.37	.16	.58	52
6	3279	Sept. 16, 1930	78.3	.19	2.00	2.05	3.20	2.55	.43	4.27	59
7	3232	Aug. 28, 1930	140	.06	1.60	6.95	4.08	6.60	1.01	5.02	40
8	3233	do	248	.05	1.70	16.30	5.48	13.17	2.08	8.23	35
9	2910	June 21, 1930	44.3	.02	1.60	1.20	.48	.33	.15	2.80	85
10	3236	Aug. 28, 1930	46.6	.04	1.40	2.25	1.02	.53	.13	4.01	86
	3235	do	126	.39	1.70	4.20	5.95	2.88	.69	8.28	70
11	3231	do	433	.17	3.10	21.20	23.51	26.60	4.01	17.20	36
12	3230	do	236	.17	1.95	9.50	13.05	12.21	.94	11.35	46
13	3229	do	205	.20	2.60	8.05	10.66	11.40	9.08	.83	4
14	3422	Oct. 16, 1930	359	.39	2.40	15.80	20.13	17.60	2.24	18.49	48
15	3423	do	285	1.01	4.15	9.50	16.16	11.02	1.68	17.11	57
16	3421	do	214	.83	3.95	6.60	13.04	9.37	2.36	11.86	50
17	2909	June 21, 1930	444	2.02	4.95	18.00	25.93	18.05	2.99	27.84	57
18	3234	Aug. 28, 1930	46.7	.03	1.30	2.25	.86	.46	.11	3.54	86
19	3239	do	191	.79	3.50	6.20	10.66	7.85	.91	11.60	54
20	3237	do	166	1.26	3.45	3.60	9.27	3.44	.57	12.31	75
21	3238	do	184	1.50	4.90	3.25	10.92	5.06	.98	13.03	68
Miscellaneous [1]	6346	June 21, 1932	32.3	.11	1.20	1.70	T [2]	.27	.16	2.48	85

[1] Outside of quadrangle; included for convenience.
[2] T = trace.

DESCRIPTION OF SAMPLES OF QUADRANGLE 29 (TABLE 37 AND FIG. 27)

Location 1, sample 4522. Delano municipal well. Drilled to 1,100 feet; filled to 600 feet because of sanding; casing perforated below 300 feet; static level, 100 feet. Deeper water reported to have had sulphur odor.

Location 2, sample 4520. Wasco municipal. Two adjacent wells; depth, 600 feet; static level, 110 feet; casing not perforated.

Location 3, sample 624. United States Cotton Field Station, Shafter. SE¼ sec. 33, T. 27 S., R. 25 E. The older of two wells. Depth, 165 feet; static level, 72 feet in May, 1927; discharge 1.2 cubic feet per second. Collected by C. S. Scofield.

Location 4, sample 4521. Southern Pacific depot well at Famosa. Depth, about 200 feet; static level, 140 feet.

Location 5–S, sample 2911. Kern River, as sampled from Beardsley Canal, opposite Lerdo.

Location 6, sample 3279. Dow station, Associated Pipe Line Co. Depth not ascertained; engineer reported they were drawing water from about 130 feet.

Location 7, sample 3232. Lerdo Land Co., well no. 4. Near SE corner NW¼ sec. 15, T. 28 S., R. 26 E. Depth, 275 feet; casing perforated below 100 feet.

Location 8, sample 3233. Lerdo School. Near NE corner SW¼ sec. 14, T. 28 S., R. 26 E. Depth, 250 feet; casing perforated below 160 feet.

Location 9, sample 2910. Lerdo Land Co., well no. 17. NE¼ sec. 14, T. 28 S., R. 26 E. Depth, 441 feet; static level, 131 feet; perforated in "hot sand" at 285 feet and below 375 feet; discharge, 2.8 cubic feet per second; mild sulphur odor.

Location 10, sample 3236. Lerdo Mutual well no. 1-B. SE¼ sec. 24, T. 28 S., R. 26 E. Depth, 470 feet; casing perforated below 100 feet.

Location 10, sample 3235. Lerdo Mutual well no. 1. SE¼ sec. 24, T. 28 S., R. 26 E. Depth, 555 feet; casing perforated below 100 feet.

Location 11, sample 3231. N. N. Brown, irrigation well. E½NW¼ sec. 22, T. 28 S., R. 26 E. Depth, 250 feet.

Location 12, sample 3230. Lerdo Land Co., well no. 10. Near NE corner sec. 22, T. 28 S., R. 26 E. Depth, 535 feet; casing perforated at several strata, upper about 105 feet.

Location 13, sample 3229. Lerdo Land Co., well no. 19. Near center sec. 22, T. 28 S., R. 26 E. Depth, 170 feet; perforated below 100 feet.

Location 14, sample 3422. Ben Arkalian ranch. East center sec. 23, T. 28 S., R. 26 E. Collected by C. S. Scofield.

Location 15, sample 3423. W. K. Lee ranch no. 2. Sec. 25, T. 28 S., R. 26 E. Depth, 425 feet; discharge, 5.4 cubic feet per second. Collected by C. S. Scofield.

Location 16, sample 3421. Ben Arkalian ranch. North center sec. 26, T. 28 S., R. 26 E. Collected by C. S. Scofield.

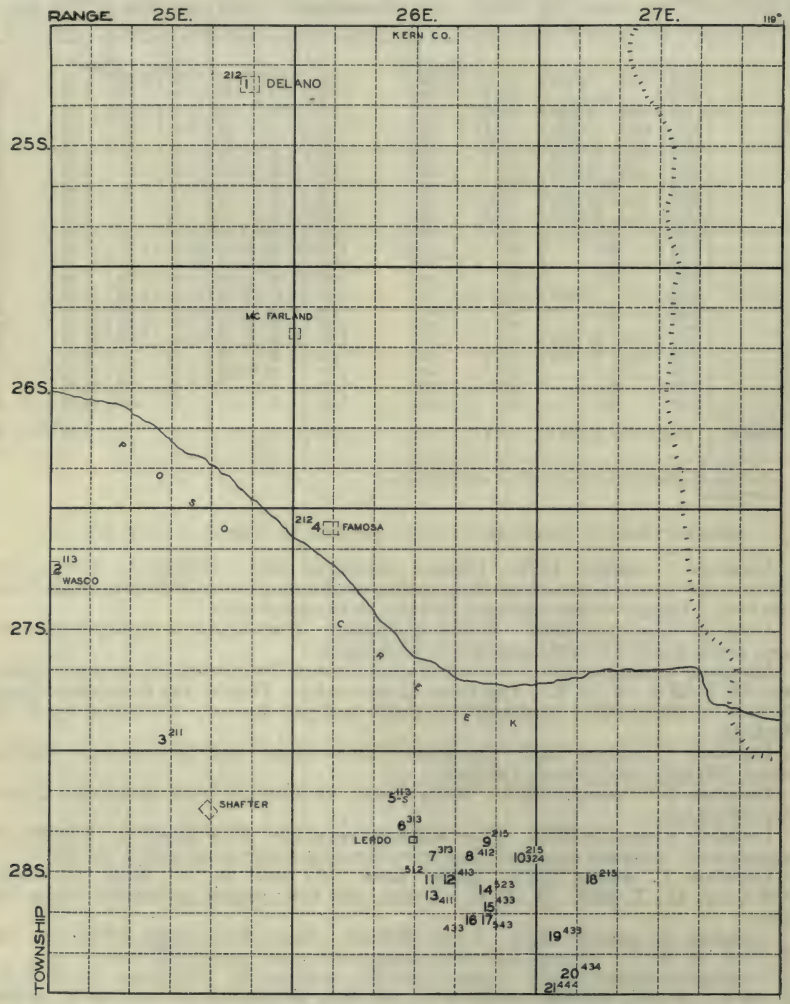

FIGURE 27.—Quadrangle 29, showing locations of samples reported in table 37.

Location 17, sample 2909. Lerdo Land Co., well no. 9–A. NE¼ sec. 26, T. 28 S., R. 26 E. Depth, 135 feet; casing perforated only near bottom; static level, 72 feet; discharge, 1.3 cubic feet per second.

Location 18, sample 3234. C. L. Clafflin, irrigation well. SW¼ sec. 20, T. 28 S., R. 27 E. Depth, 500 feet; upper casing perforations at 160 feet; static level, 160 feet. Sulphur odor, with considerable gas.

Location 19, sample 3239. W. K. Lee, irrigation well. Near NE corner SW¼ sec. 30, T. 28 S., R. 27 E. Depth, 274 feet; upper perforations at 100 feet.

Location 20, sample 3237. L. P. Sorenson, irrigation well. Near NE corner SE ¼ sec. 31, T. 28 S., R. 27 E. Depth, 247 feet.

Location 21, sample 3238. Lerdo Land Co., well no. 20. Near SE corner SW¼ sec. 31, T. 28 S., R. 27 E. Depth, 440 feet; casing perforated below 110 feet.

Miscellaneous sample 6346. Lerdo Mutual Water Co., new no. 9 well, located near and northwest of packing house, near center SW¼ sec. 24, T. 28 S., R. 26 E. Drilled in August 1932. Depth, 765 feet; perforated below 500 feet; draws down to 121 feet. Water slightly warm, with sulphur odor and some gas. Water from this well replaces water from the now abandoned well at location 17.

TABLE 38.—*Quality of water in quadrangle 30, Tps. 29, 30, 31, and 32 S., Rs. 22, 23, and 24 E. (fig. 28)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	2743	May 20, 1930	91.6	0.47	5.55	0.75	4.15	4.37	1.39	4.69	45
2-S	2741	----do----	18.0	.19	1.45	.30	.76	.99	.30	1.22	49
3	2742	----do----	91.4	.38	5.25	.80	3.91	3.44	1.03	5.49	55
4	6906	Nov. 17, 1932	483	4.14	3.10	16.08	40.67	20.01	12.95	26.48	45
Miscellaneous [1]	2740	May 20, 1930	87.2	.23	5.55	1.60	1.03	3.96	4.18	.04	5

[1] Outside of quadrangle; included for convenience.

DESCRIPTION OF SAMPLES OF QUADRANGLE 30 (TABLE 38 AND FIG. 28)

Location 1, sample 2743. Andrew Gregg, irrigation well. SE¼ sec. 5, T. 29 S., R. 23 E. Depth, 230 feet; casing perforated below 100 feet; static level, 10 feet.

Location 2–S, sample 2741. Buttonwillow Irrigation Canal, known as Eighty-foot Canal. Sampled at highway crossing near S¼ corner sec. 15, T. 29 S., R. 23 E. Kern River gravity water.

Location 3, sample 2742. Buttonwillow municipal well. Depth, approximately 220 feet; static level, 14 feet.

Location 4, sample 6906. Southern California Gas Co. well. Near center SW¼ sec. 23, T. 32 S., R. 24 E. Depth, 730 feet; upper perforations unknown (drilled 1912 or 1913); 11⅜ inches inside casing; static level, 120 feet; temperature, approximately 60° F. Water passed through 600 feet of 2-inch tubing by means of high-pressure natural gas before sample. Collected by N. D. Hudson.

Miscellaneous sample 2740. McKittrick. Water from Associated Oil Co. wells in Little Santa Maria Valley, sec. 15, T. 30 S., R. 21 E. Composite of three wells drilled to 500 feet; casing perforated below 200 feet; static level in one at 300 feet and in another at 126 feet.

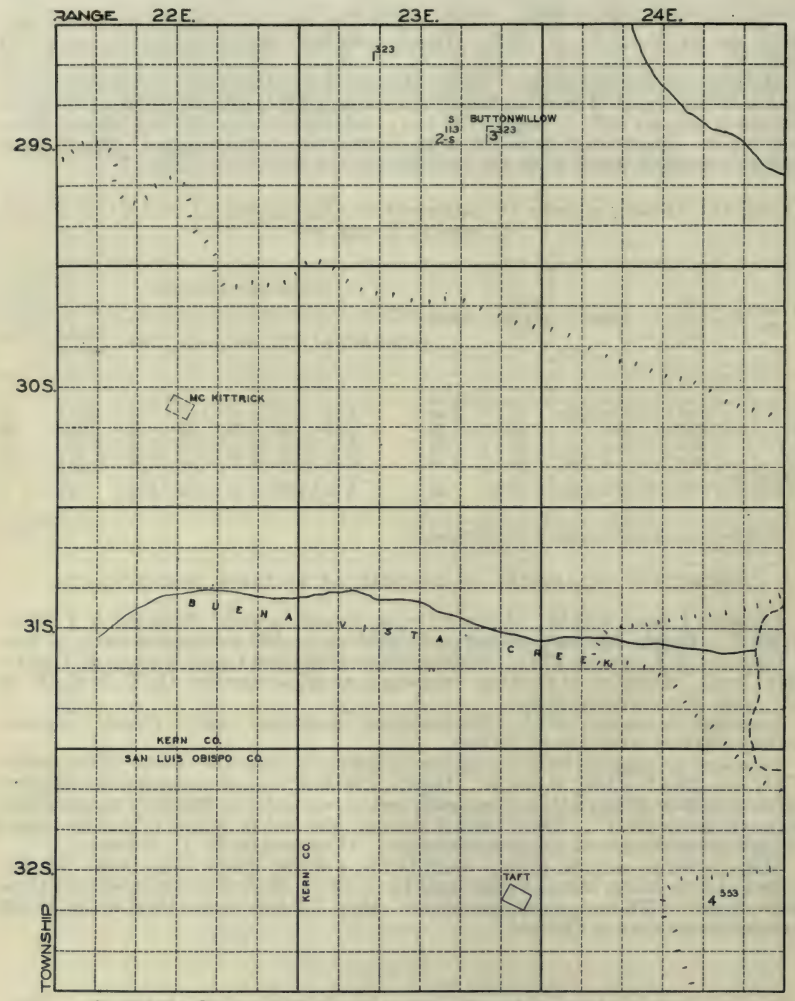

FIGURE 28.—Quadrangle 30, showing locations of samples reported in table 38.

TABLE 39.—*Quality of water in quadrangle 31, Tps. 29, 30, 31, and 32 S., Rs. 25, 26, and 27 E. (fig. 29)*

Location no.	Sample no.	Date	$K \times 10^6$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1	3760	Feb. 6, 1931	84.8	0.86	5.05	0.50	2.93	1.34	0.48	6.66	79
2	3758	-----do-----	133	.18	2.05	4.50	7.03	8.17	1.02	4.39	32
	3268	Sept. 23, 1930	202	.64	2.95	5.95	11.40	6.91	1.82	11.57	57
	3759	Feb. 6, 1931	63.9	.14	1.85	1.55	3.15	3.34	.48	2.73	42
3	2739	May 20, 1930	22.8	.18	1.45	.40	.80	.83	.16	1.66	63
4	2908	June 20, 1930	160	.51	2.80	.95	15.33	9.75	3.34	5.99	31
5	6810	Sept. 14, 1932	56.4	.39	2.20	.40	2.68	1.39	.49	3.40	64
6	6812	-----do-----	68.7	.44	2.90	.65	3.54	2.77	.81	3.55	50
7	6811	-----do-----	193	.57	3.25	.50	19.81	15.76	1.65	6.19	26
	6820	-----do-----	54.0	.43	1.85	.55	2.72	1.24	.42	3.64	69
Miscellaneous [1]	3827	Feb. 17, 1931	275	2.67	5.50	12.95	8.62	5.22	2.54	19.31	71

[1] Outside of quadrangle; included for convenience.

DESCRIPTION OF SAMPLES OF QUADRANGLE 31 (TABLE 39 AND FIG. 29)

Location 1, sample 3760. Oberlander well. NW¼SE¼ sec. 9, T. 29 S., R. 27 E. N½ of lot 18. Depth not ascertained. Collected by W. B. Robb.

Location 2, sample 3758. W. B. Robb, home well. NW¼NW¼ sec. 10, T. 29 S., R. 27 E. Depth not more than 145 feet. Collected by W. B. Robb.

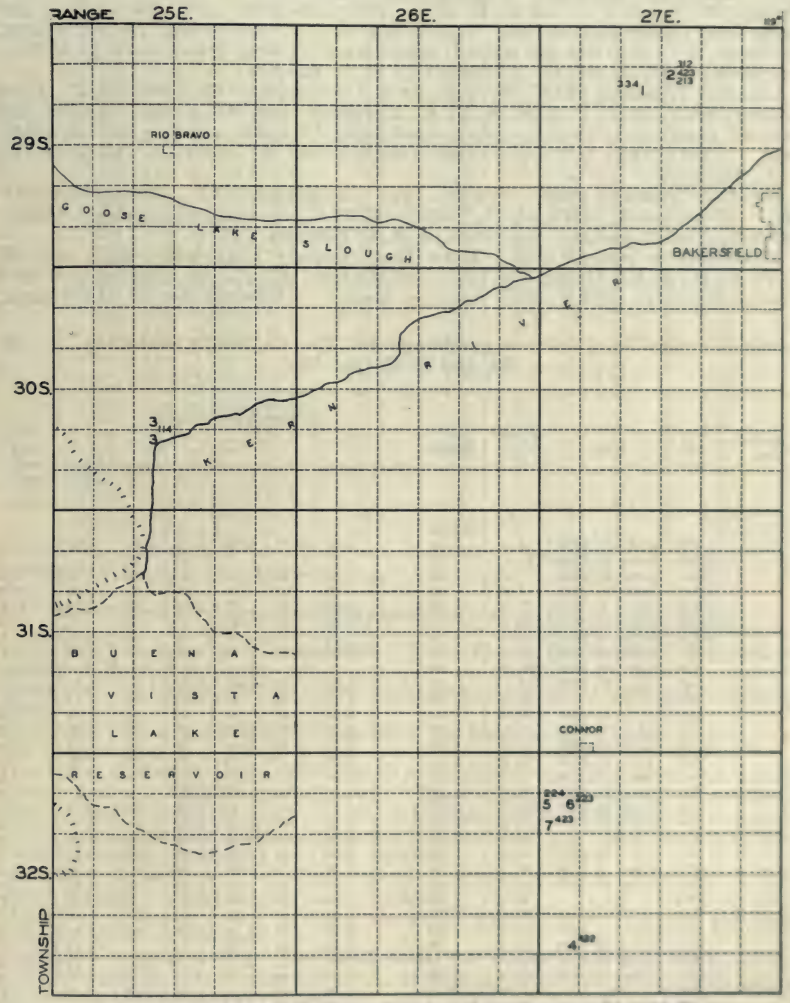

FIGURE 29.—Quadrangle 31, showing locations of samples reported in table 39.

Location 2, sample 3268. W. B. Robb well. NE¼NW¼ sec. 10, T. 29 S., R. 27 E., west of and adjacent to Southern Pacific tracks. Casing perforated from 50 to 310 feet.

Location 2, sample 3759. W. B. Robb well. Near NE corner NW¼ sec. 10, T. 29 S., R. 27 E. East of Southern Pacific tracks and highway. Depth not more than 145 feet. Collected by W. B. Robb.

Location 3, sample 2739. Taft municipal. From Western Water Works wells in sections 21 and 28, T. 30 S., R. 25 E. Depth, 280 to 450 feet; surface elevation at wells, 300 feet; Taft elevation; 1,000 feet.

Location 4, sample 2908. John H. Balbach well. E½SE¼ sec. 30, T. 32 S., R. 27 E. Depth, not less than 210 feet; static level, 14 feet.

Location 5, sample 6810. Symons Bros. Development Co., well no. 1. Kern County, NE¼ sec. 7, T. 32 S., R. 27 E.; 100 yards from north side, in center. Depth, 800 feet; 16-inch casing; discharge, 2.2 cubic feet per second; flowing well; draws down to 85 feet; temperature, 55° or 60° F.; sulphur odor; no gas; clear. Irrigates 160 to 200 acres. Collected by R. L. Sanders.

Location 6, sample 6812. Symons Bros. Development Co., well no. 3. Kern County, NE¼ sec. 7, T. 32 S., R. 27 E., 200 yards from north section line, 200 yards from center section line. Depth, 600 feet; all perforated; 18-inch casing; discharge, 3.6 cubic feet per second; static level, 12 feet; draws down to 45 feet; temperature, 55° or 60° F. Collected by R. L. Sanders.

Location 7, sample 6811. Symons Bros. Development Co., well no. 2. Kern County, SW¼ sec. 7, T. 32 S., R. 27 E., 150 yards from NE corner. Depth, 237 feet; all perforated; 14-inch casing; discharge, 2.8 cubic feet per second; static level, 12 feet; draws down to 45 feet; temperature, 55° or 60° F. Collected by R. L. Sanders.

Location 7, sample 6820. Symons Bros. Development Co., flowing domestic well. Kern County, SW¼ sec. 7, T. 32 S., R. 27 E., in corner of quarter. Depth, 800 feet; 10-inch casing. Collected by R. L. Sanders.

Miscellaneous sample 3827. Kern River County Park well. SE¼ sec. 36, T. 28, S., R. 28 E. Depth, 755 feet; temperature, 90° F. An artesian well with flowing discharge of 0.5 cubic foot per second. Collected by N. D. Hudson.

TABLE 40.—*Quality of water in quadrangle 32, Tps. 29, 30, 31, and 32 S., Rs. 28, 29, and 30 E. (fig. 30)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1-S	952	Apr. 26, 1929	15.9	0.35	1.20	0.30	0.20	0.72	0.03	0.95	56
	1380	June 23, 1929	11.1	.17	.57			.43	.00		
2	2911	June 21, 1930	7.71	.03	.70	.10	.31	.37	.16	.58	52
	6345	June 21, 1932	7.51	.05	.60	.05	T [1]	.41	.23	.18	22
	1958	Oct. 8, 1929	27.7	.23	1.80	.35	.57	1.27	.06	1.39	51
	3424	Oct. 17, 1930	22.1	.15	1.30	.35	.38	.95	.33	.75	37
	4519	July 6, 1931	18.4	.19	1.45	.20	.17	.85	.29	.68	37
3	626	Feb. 6, 1929	67.6	.27	4.00	1.05	1.18	3.69	.45	2.09	33
4	930	Apr. 24, 1929	62.8	.43							
5	946	Apr. 25, 1929	118	.21	4.00	.90	8.00	6.62	1.56	4.72	37
6	945	do	47.9	.28	3.70	.70	.56	1.82	.00	3.14	63
7	944	Apr. 24, 1929	47.0	.82	4.01	.65	.02	.20	.00	4.48	96
8	810	Apr. 5, 1929	81.6	6.66	2.39	2.53	2.63	.28	.03	7.24	93
	1379	June 23, 1929	81.8	6.58	2.26	2.49	2.64	.28	.00	7.11	96
9	943	Apr. 24, 1929	53.8	7.51	3.36	1.70	.24	.44	.00	4.86	92
10	1945	Oct. 6, 1929	47.7	.21	3.00	.65	1.21	2.33	.16	2.37	49
11	931	Apr. 24, 1929	66.6	.20	4.15	.86	1.35	3.14	1.31	1.91	30
12	1400	June 24, 1929	62.9	.31	4.42	.65	1.42	3.24	.96	2.29	35
13	948	Apr. 25, 1929	63.2	.40	4.50	.90	1.43	3.19	.90	2.74	33
14	949	do	63.5	.61	3.80	1.00	1.59	2.92	.58	2.89	45
15	932	Apr. 24, 1929	65.2	.26	3.90	.80	1.50	3.01	1.81	1.38	22
16	625	Feb. 6, 1929	91.1	.60	5.70	1.20	2.97	4.65	1.07	4.15	43
17	1381	June 24, 1929	55.5	.47	3.70	.68	1.29	2.51	.29	2.87	51
18	1399	do	48.1	.51	2.59	.65	1.01	1.97	.29	1.99	47
19	1384	do	32.6	.24	1.92	.28	.54	.98	T [1]	1.76	64
20	813	Apr. 5, 1929	52.5	.49	3.23	.74	1.16	2.38	.28	2.47	48
21	1398	June 24, 1929	32.2	.29	2.48	.37	.60	1.27	.01	2.17	63
22	941	Apr. 24, 1929	101	1.51	5.25	2.11	2.13	4.46	1.31	3.72	39
	1397	June 24, 1929	99.9	1.89	3.36	2.08	2.75	4.57	1.36	2.26	28
23	1396	do	74.9	2.37	2.88	1.59	1.34	2.91	1.03	1.87	32
24	805	Apr. 5, 1929	78.5	4.51	2.26	1.98	1.14	2.30	.38	2.70	50
	938	Apr. 24, 1929	55.0	4.43	2.50	1.50	.63	1.28	.25	3.10	67
	1378	June 23, 1929	53.5	4.63	2.46	1.32	.71	1.20	.16	3.13	70
	1838	Sept. 23, 1929	83.4	4.63	2.40	2.10	1.49	2.87	.35	2.77	46
25	815	Apr. 5, 1929	61.0	1.94	2.94	1.38	.75	2.23	.50	2.34	46
	1395	June 24, 1929	64.9	2.18	2.88	1.45	1.11	2.39	.45	2.60	48
26	940	Apr. 24, 1929	51.1	1.61	3.60	1.10	.20	1.49	.33	3.08	63
	1394	June 24, 1929	51.1	1.31	3.35	1.05	.24	1.61	.42	2.61	56
27	806	Apr. 5, 1929	53.2	.62	2.69	1.02	1.21	2.02	.38	2.52	41
28	1382	June 24, 1929	50.2	.28	3.04	.68	1.17	1.77	T [1]	3.12	64
29	1383	do	47.4	.50	2.70	1.59	.90	1.21	T [1]	3.98	77
30	1385	do	30.9	.21	2.47	.60	.27	1.49	.13	1.72	51
31	5817	Mar. 21, 1932	37.8	.08	2.75	.35	.29	1.54	.65	1.31	37
32	1386	June 24, 1929	31.5	.14	2.60	.27	.32	.13	1.28	1.78	56
33	5823	Mar. 22, 1932	32.1	.06	2.85	.40	.30	1.66	.63	1.34	37

[1] T = Trace.

TABLE 40.—*Quality of water in quadrangle 32, Tps. 29, 30, 31, and 32 S., Rs. 28, 29, and 30 E. (fig. 30)*—Continued

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						Percent sodium
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
34	935	Apr. 24, 1929	51.0	.12	2.82	1.15	0.72	2.34	0.49	1.86	40
35	936	do	34.8	.16	2.70	.40	.36	1.25	.25	1.96	57
36	937	do	104	.18	3.10	3.20	3.17	4.39	1.48	3.60	38
37	947	Apr. 25, 1929	64.7	.31	4.30	.90	1.62	2.98	1.40	2.44	50
38	950	do	138.7	7.12							
39	811	Apr. 5, 1929	46.0	6.90	2.23	1.54	.49	.09	.06	4.11	96
	812	do	46.9	7.36	2.15	1.53	.67	.07	.03	4.25	98
40	933	Apr. 24, 1929	64.0	.33	4.42	.79	1.64	3.55	1.64	1.66	24
41	814	Apr. 5, 1929	66.4	.54	4.09	.82	1.65	3.21	1.42	1.93	29
	804	do	63.0	.33	4.39	.71	1.44	3.12	1.42	2.00	31
	3278	Sept. 15, 1930	62.9	.30	4.60	.60	1.35	3.07	1.52	1.96	30
42	942	Apr. 24, 1929	46.9	7.24	2.17	1.80	.40	.57	.00	3.80	87
43	808	Apr. 5, 1929	41.3	4.64	2.54	1.27	.34	.98	.41	2.76	67
44	1393	June 24, 1929	41.5	1.13	2.93	.77	.32	1.02	.09	2.91	72
45	939	Apr. 24, 1929	49.0	.31	3.30	.90	.39	1.57	.33	2.69	59
	1392	June 24, 1929	53.6	.45	3.72	.72	.55	2.06	.77	2.16	43
46	934	Apr. 24, 1929	51.2	3.52	2.80	1.40	.42	1.87	.49	2.26	49
47	807	Apr. 5, 1929	41.6	.96	2.73	.88	.50	.81	.28	3.02	73
48	1391	June 24, 1929	43.1	.19	2.83	.42	.67	1.87	.16	1.89	48
49	3914	Apr. 1, 1931	31.4	.04	2.45	.45	.27	1.65	.82	.70	22
50	1387	June 24, 1929	36.1	.21	2.94	.37	.22	2.00	.71	.82	23
51	2907	June 20, 1930	46.3	.19	3.30	.50	1.44	1.80	.83	2.61	50
52	1390	June 24, 1929	50.6	.55	1.53	1.26	1.25	1.11	.00	2.93	73
53	1389	do	55.6	.56	1.50	2.07	1.31	.98	.00	3.90	80
54	1388	do	39.0	1.60	3.05	.62	.49	.09	.00	4.07	98
55	5908	Apr. 14, 1932	73.1	.17	2.25	2.05	2.32	4.40	1.51	1.80	23
Miscellaneous [1]	928	Apr. 23, 1929	134	.87	5.69	1.92	7.33	4.98	5.66	4.30	29
	926	do	113	.25	5.11	1.65	5.31	5.42	3.38	3.27	27
	3915	Apr. 1, 1931	69.4	.71	4.85	.35	1.85	2.04	1.42	3.59	51
	6827	Oct. 17, 1932	49.0	.13	1.25	2.45	.79	.78	.18	3.55	78
	6828	do	75.2	.33	1.65	4.13	1.15	2.46	.47	4.05	58

[1] Outside of quadrangle; included for convenience.

DESCRIPTION OF SAMPLES OF QUADRANGLE 32 (TABLE 40 AND FIG. 30)

Location 1–S, samples 952 and 1380. Kern River, Bakersfield. Sampled at heading of East Side Canal.

Location 1–S, sample 2911. Kern River, Beardsley Canal. Sampled opposite Lerdo.

Location 1–S, sample 6345. Kern River at Bakersfield. River was high at time of sampling.

Location 2, sample 1958. Bakersfield municipal. Sampled at service station opposite tower. Well source unknown. There are a large number of scattered pumping stations which pump directly into Bakersfield municipal water mains.

Location 2, sample 3424. Bakersfield municipal, tap at Seventeenth and Chester Streets. Collected by C. S. Scofield.

Location 2, sample 4519. Bakersfield municipal, tap at Seventeenth and Center Streets. Collected by C. S. Scofield.

Location 3, sample 626. Edison domestic supply well. Depth, 160 feet. Collected by C. S. Scofield.

Location 4, sample 930. Goff well, near NE corner SE¼ sec. 33, T. 30 S., R. 29 E. Depth, 400 feet; static level, 85 feet; approximate water table elevation, 390 feet; draws down 45 feet.

Location 5, sample 946. A. Brown Co. well. SE¼SE¼ sec. 5, T. 30 S., R. 30 E. Depth, 565 feet; static level, 375 feet; water table elevation, 690 feet; discharge, 0.2 cubic foot per second; temperature, 79° F.

Location 6, sample 945. Jack Bowman, domestic well. SE¼ sec. 8, T. 30 S., R. 30 E. Depth, 355 feet; static level, 160 feet; approximate water table elevation, 740 feet.

Location 7, sample 944. Deemer abandoned irrigation well. Near center sec. 17, T. 30 S., R. 30 E., in Caliente Wash. Depth not ascertained; static level, 134 feet; approximate elevation of water table, 636 feet.

Location 8, samples 810 and 1379. M. F. Newmarkel well. Near SE corner sec. 20, T. 30 S., R. 30 E. Depth, 387 feet; static level, 126 feet; approximate elevation of water table, 664 feet. Sample 810 collected by C. S. Scofield.

Location 9, sample 943. Shallow well at location sometimes known as "Deemer Spring." NE¼ sec. 33, T. 30 S., R. 30 E. Bailed sample. Surface elevation approximately 720 feet; water table several feet below.

Location 10, sample 1945. Ed Joiner service station well. Near SE corner sec. 18, T. 31 S., R. 28 E. Depth, 41 feet.

Location 11, sample 931. Earl Fruit Co. well. NE corner sec. 4, T. 31 S., R. 29 E. Static level, 120 feet; water table elevation, 355 feet.

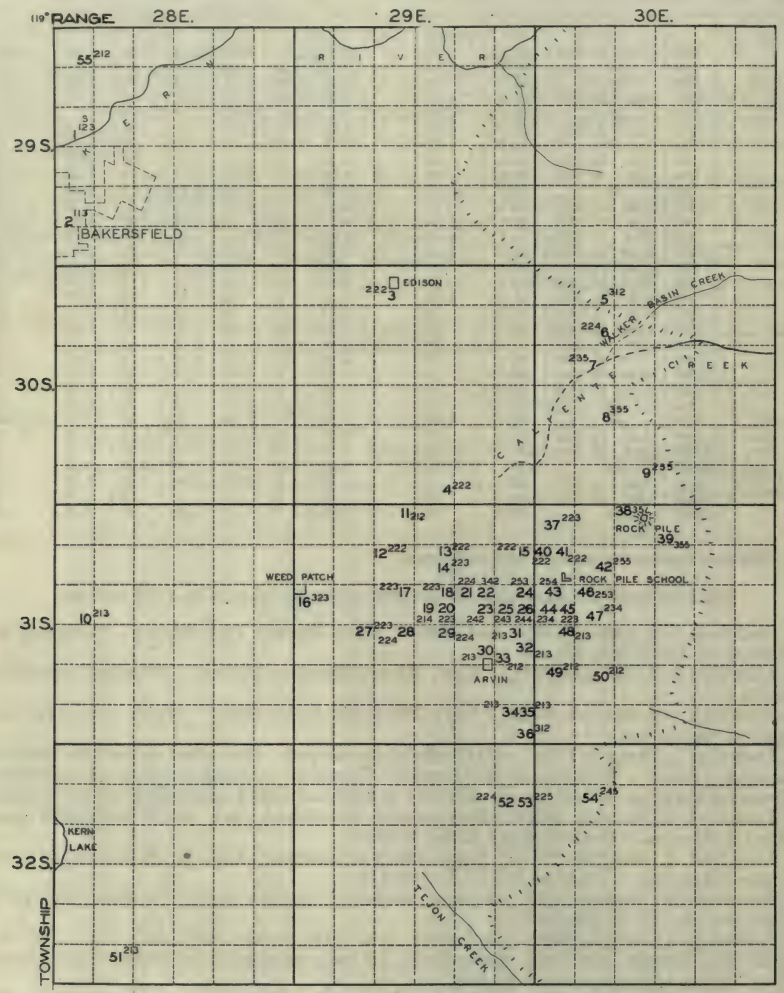

FIGURE 30.—Quadrangle 32, showing locations of samples reported in table 40.

Location 12, sample 1400. Irrigation well. Near NW corner sec. 9, T. 31 S., R. 29 E. Characteristics of well not ascertained.

Location 13, sample 948. Earl Fruit Co. well. Near NE corner sec. 10, T. 31 S., R. 29 E., just west of the edge of old Caliente Wash.

Location 14, sample 949. Earl Fruit Co., irrigation well. NE corner SE¼ sec. 10, T. 31 S., R. 29 E.

Location 15, sample 932. Earl Fruit Co., irrigation well. NE corner sec. 12, T. 31 S., R. 29 E. Depth, 424 feet; static level, 185 feet; approximate water table elevation, 360 feet; draws down 19 feet; discharge, 6.7 cubic feet per second.

Location 16, sample 625. Hoover well. NW¼ sec. 18, T. 31 S., R. 29 E. Static level, 50 to 60 feet. Collected by C. S. Scofield.

Location 17, sample 1381. H. S. Jewett well. Near NE corner sec. 16, T. 31 S., R. 29 E. Depth, 635 feet; static level, 110 feet; draws down 25 feet; discharge, 2.5 cubic feet per second.

Location 18, sample 1399. P. H. Greene Co. well. NE corner sec. 15, T. 31 S., R. 29 E. Depth, 407 feet; static level, 150 feet; discharge, 3.0 cubic feet per second.

Location 19, sample 1384. H. S. Jewett well. Near NE corner SW¼ sec. 15, T. 31 S., R. 29 E. Depth, 700 feet; static level, 110 feet; draws down 50 feet; discharge, 2.0 cubic feet per second.

Location 20, sample 813. C. Yanssey well. Near E¼ corner sec. 15, T. 31 S., R. 29 E. Static level, 105 feet; approximate elevation of water table, 360 feet. Collected by C. S. Scofield.

Location 21, sample 1398. P. H. Greene Co. well. Near N¼ corner sec. 14, T. 31 S., R. 29 E. Depth, 550 feet; discharge, 3.0 cubic feet per second. This well perforates a clay stratum in which sample 1399 ended.

Location 22, samples 941 and 1397. Hannon well. NE corner sec. 14, T. 31 S., R. 29 E. Depth, 320 feet; static level, 140 feet; approximate elevation of water table, 355 feet; discharge, 2.7 cubic feet per second.

Location 23, sample 1396. Irrigation well. NE corner SE¼ sec. 14, T. 31 S., R. 29 E.

Location 24, samples 805, 938, 1378, and 1838. Earl Fruit Co. well no. 2. NE corner sec. 13, T. 31 S., R. 29 E. Depth, 240 feet; static level, 142 feet; draws down 27 feet; discharge, 5.7 cubic feet per second; warm. This well has sulphur odor, is now capped, and is adjacent to a previously capped well, 450 feet deep, with a perforated casing.

Location 25, samples 815 and 1395. Edmundson well. NW corner SW¼ sec. 13, T. 31 S., R. 29 E. Static level, 135 feet; elevation of water table, approximately 355 feet. Sample 815 collected by C. S. Scofield.

Location 26, samples 940 and 1394. Daly well. NW corner NE¼SE¼ sec. 13, T. 31 S., R. 29 E. Static level, 113 feet; elevation of water table, 377 feet; discharge, 2.9 cubic feet per second.

Location 27, sample 806. Brewster well no. 3. NE corner sec. 20, T. 31 S., R. 29 E. Static level, 155 feet; elevation of water table, approximately 260 feet. Collected by C. S. Scofield.

Location 28, sample 1382. Irrigation well. Near NE corner sec. 21, T. 31 S., R. 29 E. Well operating; characteristics not ascertained.

Location 29, sample 1383. Richards, Pauley & Krauter well. NE corner sec. 22, T. 31 S., R. 29 E. Well operating; characteristics not determined.

Location 30, sample 1385. Stenderup-Jewett well. NE corner SE¼ sec. 23, T. 31 S., R. 29 E. Depth, 390 feet; static level, 100 feet; draws down 40 feet.

Location 31, sample 5817. Bear Mountain Orange Co. north well; 1,000 feet west of NE corner sec. 24, T. 31 S., R. 29 E. Collected by H. G. Clardy.

Location 32, sample 1386. Bear Mountain Orange Co., NE corner SE¼ sec. 24, T. 31 S., R. 29 E.

Location 33, sample 5823. H. G. Clardy well. Bear Mountain subdivision, 337 feet west of NE corner of S½SW¼ sec. 24, T. 31 S., R. 29 E. Depth, 519 feet; casing perforated from 300 to 500 feet; principal gravel stratum, 450 to 500 feet; discharge, 2 cubic feet per second. Collected by H. G. Clardy.

Location 34, sample 935. Earl Fruit Co. NW corner NE¼ sec. 36, T. 31 S., R. 29 E. Depth, 525 feet; static level, 60 feet; elevation of water table, approximately 360 feet; discharge, 0.7 cubic foot per second.

Location 35, sample 936. Earl Fruit Co. NE corner sec. 36, T. 31 S., R. 29 E. Depth, 400 feet; static level, 60 feet; discharge, 0.7 cubic foot per second.

Location 36, sample 937. Earl Fruit Co. SE corner NE¼ sec. 36, T. 31 S., R. 29 E. Depth, 385 feet; static level, 40 feet; approximate elevation of water table, 375 feet; discharge, 3.6 cubic feet per second.

Location 37, sample 947. Earl Fruit Co. NE corner SW¼ sec. 6, T. 31 S., R. 30 E. Static level, 190 feet; elevation of water table, approximately 375 feet.

Location 38, sample 950. Abandoned well. NW corner sec. 4, T. 31 S., R. 30 E. Static level, 255 feet; elevation of water table, as measured in casing when bailed, was 360 feet, but sound in the well indicated that water from a higher water table was running into casing through a crack or through higher perforations. Sample too small for complete analysis. It is probable that the bailed sample represented an upper stratum.

Location 39, sample 811. Tejon Spring, El Tejon Rancho. SW¼ sec. 3, T. 31 S., R. 30 E. Discharge, 0.04 cubic foot per second; temperature, 100° F. Elevation approximately 600 feet. Sample collected by C. S. Scofield. Sample 812. Reservoir supplied by Tejon Spring. Collected by C. S. Scofield.

Location 40, sample 933. Earl Fruit Co. NE corner NW¼ sec. 7, T. 31 S., R. 30 E. Elevation of water table, 360 feet; discharge, 4 cubic feet per second.

Location 41, sample 814. Earl Fruit Co. NE¼ sec. 7, T. 31 S., R. 30 E., 1,800 feet west of NE corner. Depth, 430 feet; static level, 184 feet; elevation of water table, 366 feet. Collected by C. S. Scofield.

Location 41, samples 804 and 3278. Lewis well. NE corner sec. 7, T. 31 S., R. 30 E. Discharge, 3.6 cubic feet per second. Collected by C. S. Scofield.

Location 42, sample 942. Valley Farms Co. abandoned well. NE corner SE¼ sec. 8, T. 31 S., R. 30 E. Static level, about 170 feet; elevation of water table, about 360 feet.

Location 43, sample 808. Small well. Near center north line sec. 18, T. 31 S., R. 30 E. Depth, 385 feet; static level, 135 feet; elevation of water table, 365 feet; discharge, 2.0 cubic feet per second. Collected by C. S. Scofield.

Location 44, sample 1393. Irrigation well. SW corner NE¼ sec. 18, T. 31 S., R. 30 E.

Location 45, samples 939 and 1392. Dan Moore well. Near NW corner NE¼SE¼ sec. 18, T. 31 S., R. 30 E. Depth, 400 feet; static level, 145 feet; elevation of water table, 355 feet; discharge, 2 cubic feet per second.

Location 46, sample 934. Giffen well, abandoned. NW corner sec. 17, T. 31 S., R. 30 E. Drilled in 1920; depth, 460 feet; static level, 178 feet; approximate elevation of water table, 337 feet; discharge, 1.8 cubic feet per second.

Location 47, sample 807. McCowan irrigation well. Near center sec. 17, T. 31 S., R. 30 E. Static level, 140 feet; approximate elevation of water table, 360 feet; discharge, 3.8 cubic feet per second; temperature, 82° F. Collected by C. S. Scofield.

Location 48, sample 1391. Aaron Neff well. North of center NE¼ sec. 19, T. 31 S., R. 30 E. Depth, 383 feet; static level, 127 feet; draws down 23 feet; elevation of water table, about 350 feet.

Location 49, sample 3914. Irrigation well, drilled in 1930. North of center sec. 30, T. 31 S., R. 30 E. Depth, 800 feet. Collected by C. S. Scofield.

Location 50, sample 1387. Kern Oil Co. stock well. North of center NE¼ sec. 29, T. 31 S., R. 30 E. Depth, 350 feet; static level, 125 feet; approximate elevation of water table, 355 feet.

Location 51, sample 2907. Mary Dickas well. Sec. 32, T. 32 S., R. 28 E. Small domestic pump attached to well drilled to depth of 815 feet; casing perforated below 182 feet; static level, 22 feet.

Location 52, sample 1390. E. W. Smith well. SE corner NW¼ sec. 12, T. 32 S., R. 29 E. Depth, 500 feet; static level, 62 feet; elevation of water table, about 418 feet.

Location 53, sample 1389. J. H. Alward well. Near center south line NE¼ sec. 12, T. 32 S., R. 29 E. Depth, 700 feet; static level, 80 feet; elevation of water table, about 418 feet.

Location 54, sample 1388. Spring in Little Sycamore Canyon. NW¼ sec. 8, T. 32 S., R. 30 E. Sampled from pipe outlet at Tejon Rancho stock reservoir.

Location 55, sample 5908. Union Oil Co., irrigation well, Oildale. SE¼ sec. 6, T. 29 S., R. 28 E. Depth, 450 feet; 12-inch casing; operated by compressed air; static level, 107 feet; operating level, 117 feet. Collected by N. D. Hudson.

Miscellaneous sample 928. Caliente Creek. Sample taken from stream 1 mile east of Caliente Station. Discharge, 0.3 cubic foot per second.

Miscellaneous sample 926. Tehachapi Creek. Sample taken near SE corner sec. 17, T. 31 S., R. 32 E., approximately one-half mile north of Keene post office. Discharge, 2 cubic feet per second.

Miscellaneous sample 3915. Ranch well, operated by windmill. East of gravel pit on south side of Tehachapi-Mojave highway, about 2½ miles east of Monolith. Sec. 28, T. 32 S., R. 34 E. Collected by C. S. Scofield.

Miscellaneous sample 6827. E. O. Mitchell well no. 1. Middle of north line, sec. 22, T. 31 S., R. 29 E. Pumped with 50-hp. motor; 10-inch discharge pipe, half full. Collected by N. D. Hudson.

Miscellaneous sample 6828. E. O. Mitchell well no. 2. NE corner SW 80 acres sec. 22, T. 31 S., R. 29 E. Pumped with 50-hp. motor; 10-inch discharge pipe; discharge, 2.4 cubic feet per second. Collected by N. D. Hudson.

TABLE 41.—*Quality of water in quadrangle 33, Tps. 11, 10, 9, and 8 N., Rs. 26, 25, and 24 W.*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						
					CO_3+ HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	"Percent sodium"
				P.p.m.							
1	2738	May 19, 1930	2,076	49.80	64.85	166.00	0.26	4.32	9.76	216.63	94
2	2736	do	184	.23	3.30	.35	17.81	2.21	7.31	1.94	9
Miscellaneous[1]	2737	do	49.6	.23	3.20	.60	.63	2.33	.93	1.17	26

[1] Outside of quadrangle; included for convenience.

DESCRIPTION OF SAMPLES OF QUADRANGLE 33 (TABLE 41)

(Quadrangle map not shown)

Location 1, sample 2738. Northern Oil Co. Water brought up with oil from 12 wells drilled to 1,000 feet. NW¼ sec. 1, T. 11 N., R. 24 W.

Location 2, sample 2736. Cuyama Ranch. Cuyama no. 2 grant. Location corresponds to sec. 2, T. 10 N., R. 26 W. Reservoir composite of water from stream bed sand and 14 springs. Some springs reported as warm and with sulphur odor.

Miscellaneous sample 2737. Springs at Ozena. Sec. 19, T. 7 N., R. 23 W., San Bernardino base and meridian. Sample from water piped to Maricopa. Ozena is near head of Cuyama River.

TABLE 42.—*Quality of water in quadrangle 34, Tps. 11, 10, 9, and 8 N., Rs. 23, 22, and 21 W. (fig. 31)*

Location no.	Sample no.	Date	$K \times 10^5$ at 25° C.	Boron	Milligram equivalents						
					CO_3+HCO_3	Cl	SO_4	Ca	Mg	Alkali bases	"Percent sodium"
				P.p.m.							
1-S	2710	Apr. 27, 1930	192	0.93	4.95	1.50	15.73	11.00	7.92	3.26	15
2	2706	do	188	.92	4.10	1.55	16.67	9.45	8.37	4.50	20
3-S	2707	do	190	.90	5.20	1.35	16.21	9.62	7.66	5.48	24
4-S	2708	do	187	1.17	4.95	1.30	15.23	9.34	7.35	4.79	22
5-S	2709	do	105	.64	5.25	.35	7.33	4.85	5.42	2.68	21

DESCRIPTION OF SAMPLES OF QUADRANGLE 34 (TABLE 42 AND FIG. 31)

Location 1–S, sample 2710. San Emigdio Creek as diverted at San Emigdio Ranch. SW¼ sec. 36, T. 11 N., R. 22 W., San Bernardino base and meridian. Discharge, 0.3 cubic foot per second. Collected by V. G. Ryland.

Location 2, sample 2706. Adobe Spring, San Emigdio Creek. In unsurveyed area; position corresponds to SW corner sec. 1, T. 10 N., R. 22 W. Discharge, 0.15 cubic foot per second. Collected by V. G. Ryland.

Location 3–S, sample 2707. San Emigdio Creek. Corresponds to E¼ corner sec. 12, T. 10 N., R. 22 W. Discharge, 0.4 cubic foot per second. Collected by V. G. Ryland.

Location 4–S, sample 2708. San Emigdio Creek, Barley Flats. Corresponds to SW corner sec. 13, T. 10 N., R. 22 W. Discharge, 0.5 cubic foot per second. Collected by V. G. Ryland.

Location 5–S, sample 2709. San Emigdio Creek, Douglas Place. SE¼ sec. 5, T. 9 N., R. 21 W. Discharge, 0.36 cubic foot per second. Collected by V. G. Ryland.

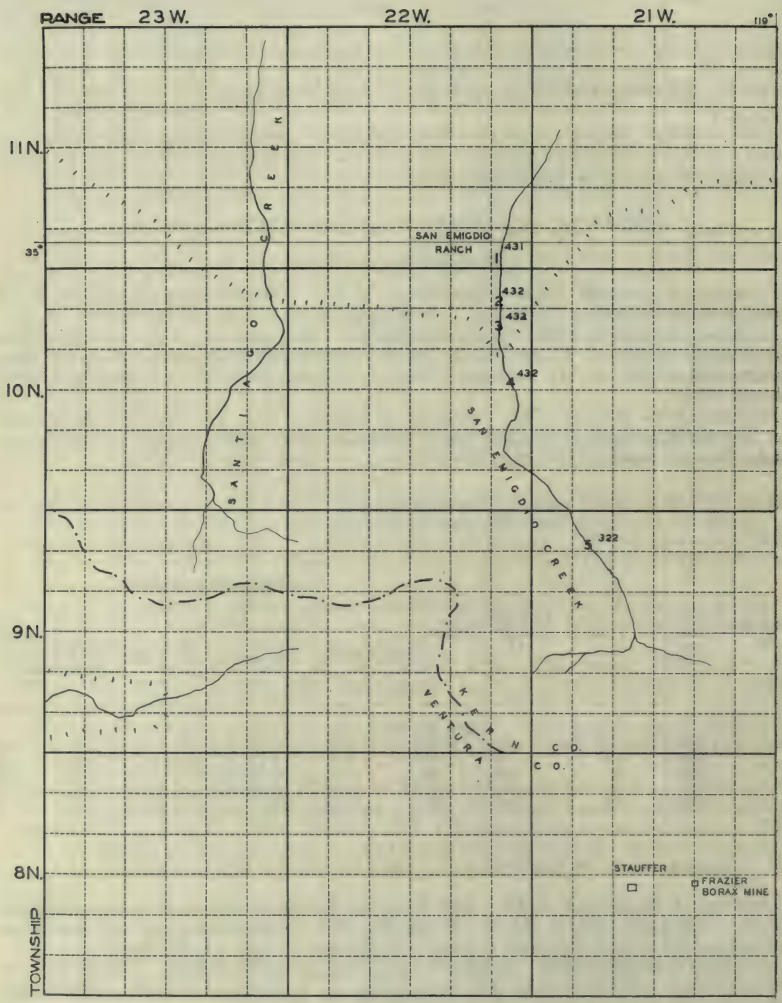

FIGURE 31.—Quadrangle 34, showing locations of samples reported in table 42.

TABLE 43.—*Quality of water in quadrangle 35, Tps. 11, 10, 9, and 8 N., Rs. 20, 19, and 18 E. (fig. 32)*

Location no.	Sample no.	Date	$K \times 10^3$ at 25° C.	Boron	Milligram equivalents						"Percent sodium"
					$CO_3 + HCO_3$	Cl	SO_4	Ca	Mg	Alkali bases	
				P.p.m.							
1–S	5005	Oct. 16, 1931	47.5	0.40	4.40	0.35	0.79	3.12	2.17	0.25	5
2	1837	Sept. 23, 1929	101	.92	6.60	.90	4.90	1.93	5.90	4.57	37
3–S	1944	Oct. 6, 1929	105	.92	7.10	.85	3.89	2.03	5.37	4.44	38
4	2618	Apr. 18, 1930	138	.92	11.00	1.40	3.46	3.65	1.53	10.68	67
5	1943	Oct. 6, 1929	81.2	.60	5.60	.45	2.98	3.30	3.13	2.60	29
6	2905	June 20, 1930	80.7	.35	5.80	.50	2.78	3.37	2.51	3.20	35
7	2906	do	74.1	.51	5.30	.50	2.45	3.25	2.17	2.83	34
8–S	2619	Apr. 18, 1930	7,919	29.90	56.25	368.00	883.53	1.80	28.06	1,277.92	98
9–S	383	Nov. 11, 1928	83	.20	5.90	.70	2.18	5.00		3.78	43
10–S	380	do	60.5	5.00	3.00	.20	2.96	4.60		1.56	25
11–S	381	do	71.3	2.00	3.40	.10	4.66	5.60		2.56	31
Miscellaneous[1]	5006	Oct. 16, 1931	85.2	.15	6.85	.80	2.45	4.80	2.92	2.39	24

[1] Outside of quadrangle; included for convenience.

DESCRIPTION OF SAMPLES OF QUADRANGLE 35 (TABLE 43 AND FIG. 32)

Location 1–S, sample 5005. El Paso Creek, near El Tejon Ranch headquarters. Location corresponds to NW¼ sec. 25, T. 11 N., R. 18 W., San Bernardino base and meridian. Discharge, 0.2 cubic foot per second.

Location 2, sample 1837. Well at foot of Grapevine grade. T. 10 N., R. 19 W. Depth, 780 feet; formerly flowing. On this date, water stands 2 feet below ground surface. Section location of well not known definitely. Sampled from highway tank. Information supplied by George Brunk, highway foreman.

Location 3–S, sample 1944. Grapevine Creek. Sampled at foot of grade. Sec. 29, T. 10 N., R. 19 W. Discharge, 15 cubic feet per second.

Location 4, sample 2618. Mud Spring, Castaic Lake. Location corresponds to sec. 25, T. 9 N., R. 19 W. One of numerous small springs in the bed of Castaic Lake.

Location 5, sample 1943. Lebec village wells, sec. 35, T. 9 N., R. 19 W. Depth, 150 to 175 feet.

Location 6, sample 2905. John J. Peters, Lebec, well no. 2. NE¼ sec. 35, T. 9 N., R. 19 W. Depth, 139 feet; casing perforated at all strata.

Location 7, sample 2906. John J. Peters, Lebec, well no. 3 (800 feet south of no. 2), NE¼ sec. 35, T. 9 N., R. 19 W. Depth, 250 feet; casing perforated below 118 feet.

Location 8–S, sample 2619. Castaic Lake. Location corresponds to center sec. 25, T. 9 N., R. 19 W. Lake receding rapidly and was dry later in the summer.

Location 9–S, sample 383. Cuddy Creek, below Cuddy Ranch. SE¼ sec. 33, T. 9 N., R. 20 W. Discharge, 0.2 cubic foot per second. Small sample collected by C. S. Scofield. The boron determination is by the semiquantitative tumeric method.

Location 10–S, sample 380. Seymour Creek, one-fourth mile north of old Griffen post office. Sec. 31, T. 8 N., R. 20 W. Discharge, 1 cubic foot per second. Small sample collected by C. S. Scofield. This sample and the sample (381) from Lockwood Creek are of water tributary to Piru Creek and the Santa Clara River. Boron determination is by the semiquantitative tumeric method.

Location 11–S, sample 381. Lockwood Creek, above junction of Seymour Creek. Discharge, 2 cubic feet per second. Small sample collected by C. S. Scofield. The boron determination is by the semiquantitative tumeric method.

Miscellaneous sample 5006. Tejon Creek; sampled near location corresponding to SE corner sec. 14, T. 11 N., R. 17 W. Discharge, 0.3 cubic foot per second.

DISCUSSION OF SAN JOAQUIN VALLEY WATERS

QUADRANGLES 1 TO 4

The area embraced by quadrangles numbered 1 to 4 includes the drainage contiguous to Suisun Bay and that of the lower portions of both the San Joaquin and Sacramento Rivers.

The ground waters of this area, insofar as these may be represented by the samples collected, were found for the most part to be higher in bicarbonate than in chloride, and higher in chloride than in sulphate. The calcium and magnesium concentrations were usually about equal. Except for waters from a number of relatively deep wells, sodium constituted less than 50 percent of the bases.

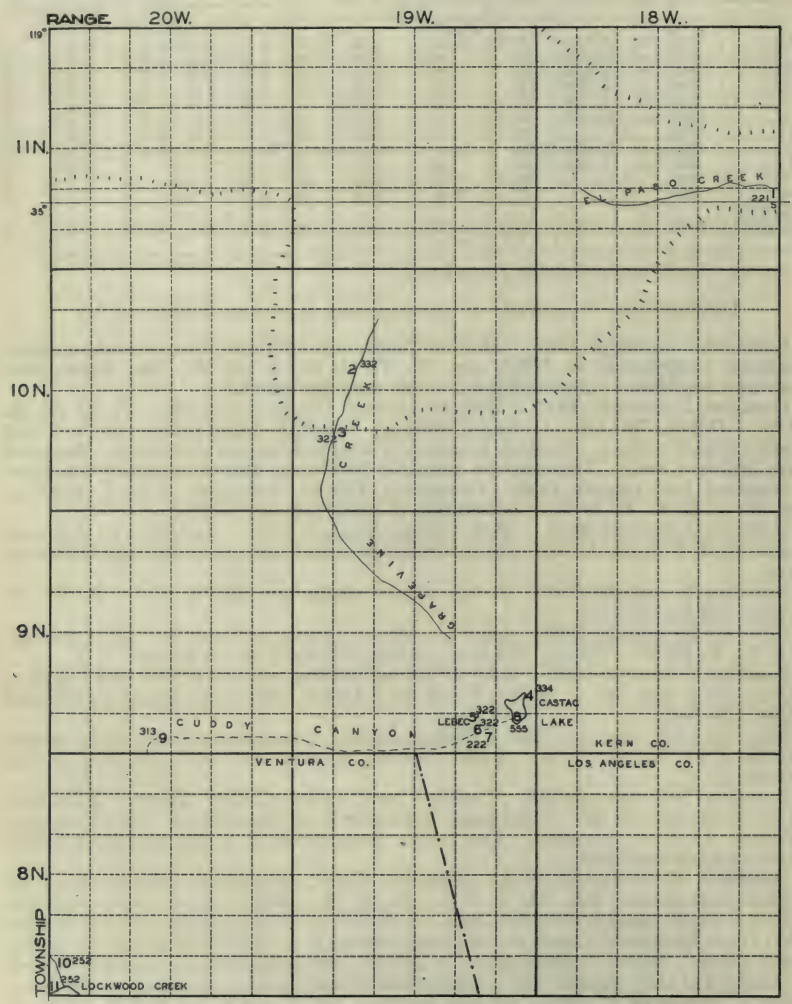

FIGURE 32.—Quadrangle 35, showing locations of samples reported in table 43.

In quadrangles 1 and 2 the greater number of the waters sampled were moderately saline. Conductances of about 80 were found for 7 of the 10 samples from quadrangle 1, and conductances usually above 100, sometimes above 200, were found for the samples from quadrangle 2. The greater number of the samples from quadrangle 3 were collected near Stockton, and most of these had conductances lower than 50. None of the 5 widely scattered samples collected in quadrangle 4 were saline.

The boron concentrations were found to be highly variable in each of these quadrangles; 3 of the 10 samples from quadrangle 1 had less than 0.5 p.p.m., and 5 had more than 1.0 p.p.m.; 4 of the 20 samples from quadrangle 2 had less than 0.5 p.p.m., and 14 had more than 1.0 p.p.m.; 12 of the 19 samples from quadrangle 3 had less than 0.5 p.p.m., and 4 had in excess of 1.0 p.p.m. No sample from quadrangle 4 had more than 0.1 p.p.m. of boron.

Water from the municipal well at Rio Vista contained 1.50 p.p.m. of boron; 3 samples from Isleton contained 0.24, 1.44, and 1.24 p.p.m.; a sample from Walnut Grove (quadrangle 3, miscellaneous) contained 0.06 p.p.m., and a sample from Thornton contained 1.06 p.p.m. These samples, representing as they do ground waters in part north of the San Joaquin River drainage, provide evidence that appreciable concentrations of boron may occur as a normal constituent in many of the ground waters of the lower Sacramento River Valley.

QUADRANGLE 1

(Tps. 1, 2, 3, and 4 N., Rs. 1, 2, and 3 W.)

The well sample from the Haag ranch south of Martinez, location 1, must be looked upon as distinctly nontypical. It was sent to the laboratory for analysis because of the adverse effects that followed immediately its use on a garden. This water, derived from a shallow well, had a conductance of 818 and contained 53.3 p.p.m. of boron. It is not possible to conclude whether the stratum tapped was once a part of a saline lagoon or whether boron and chloride had been deposited here by a once active fumarole. The magmatic gases emanating from fumaroles are commonly high in both chlorides and boron.

Like many warm springs, the water of Sulphur Spring at location 6, north of Suisun Bay, carries several parts per million of boron. Appreciable concentrations of boron are not always found in natural hot waters, but such is commonly the case. Hot springs frequently occur along fault lines, which may provide either outlets for deep-seated waters or access for subsurface waters to underlying magma or the hot gaseous emissions from them.

Samples from a few irrigation wells immediately north of this quadrangle have been found to carry several parts per million of boron. Sample 6232 at location 5 is from an old oil well, and, like many deep wells in the San Joaquin Valley, its boron content is significantly high and sodium is the principal base.

QUADRANGLE 2

(Tps. 1, 2, 3, and 4 N., Rs. 1, 2, and 3 E.)

The three Isleton samples were from wells adjacent to the Sacramento River. The first of these, from a 130-foot well, had low salinity, conductance 40.0, and little boron, 0.24 p.p.m.; that from the 211-foot well was saline, conductance 297, 23.40 milligram equivalents of chloride, and 1.44 p.p.m. of boron; it would not be suitable for most agricultural purposes. The water from the 615-foot well was of somewhat better quality (conductance 160 and boron 1.24), and it is this water that is used principally for municipal purposes. Boron symptoms on plants were pronounced in Isleton, and the effects of high percentage of sodium on the permeability of the soil were evident.

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The Pittsburg municipal water, location 3, had sufficient boron, 0.81 p.p.m., to produce mild but characteristic leaf injury. Two wells at locations 4 and 5 southeast of Pittsburg produced water with less than 0.50 p.p.m. of boron.

Boron symptoms are in evidence in and around Brentwood, and the well samples obtained in the area contained, with one exception, in excess of 1 p.p.m. of boron. Where continued use is made of certain of these well waters boron injury can be expected. The irrigation water used in this area is for the most part that diverted from the San Joaquin River, and this water has not been found to carry injurious boron concentrations. (See sample at location 16, collected in April, and the series of samples from the river below the mouth of the Tuolumne at location 5 of quadrangle 7.) The water from drainage wells installed to lower the water table has been found to be injuriously high in boron, and except as this water can be judiciously combined with large volumes of water low in boron, its reuse should be avoided. Boron injury is and has been experienced when the water table has been allowed to rise into the root zone.

Notwithstanding some variation in the depths of the different wells in the Brentwood area, the waters produced are all of the same general type; calcium and magnesium concentrations are in excess of sodium, bicarbonate exceeds chloride, and the chloride exceeds the sulphate.

QUADRANGLE 3

(Tps. 1, 2, 3, and 4 N., Rs. 4, 5, and 6 E.)

Several types of water are represented by the samples collected in Stockton. The waters produced by the deep wells, locations 8 and 10, are warm, very saline, carry a great deal of chloride and some boron, and, as in the Lodi well, sulphates are low. The absence of sulphate and the presence of gas suggest sulphate reduction by anaerobic bacteria (p. 122). The 1,040-foot well at the fiberboard plant, location 11, is relatively high in both sodium and chloride, conductance was 140, and the 1.18 p.p.m. of boron had been sufficient to produce characteristic symptoms on ornamental plantings. Boron symptoms are in evidence on many of the street and dooryard plantings in Stockton, but in general they are not of severe intensity. The water from the wells at East Sonora Street and Wilson Way, location 12, with depths from 670 to 1,070 feet, had a conductance of 62 and 0.83 p.p.m. of boron, which are both greater than found in the water from the two pump stations to the north at locations 5 and 7. The conductances of these, the Ellis Street 533-foot well and the three 700-foot wells on Monroe Street, were 32.2 and 35.5 and the boron concentrations were 0.10 and 0.66. The water from a shallow domestic well at location 6 had a conductance of 39.4 and 0.16 p.p.m. of boron. The State Hospital wells, location 9, with depths of about 600 feet, are both relatively low in solutes of all kinds. The samples collected in Stockton indicate that water of low salinity and low boron content is generally available to a depth of about 700 feet. The percentage of sodium tends to increase with depth.

QUADRANGLE 4

(Tps. 1, 2, 3, and 4 N., Rs. 7, 8, and 9 E.)

The 6 scattered samples collected in quadrangle 4, including sample 4560 repeated from quadrangle 3, are significant in the fact that in no

instance did boron occur in excess of 0.10 p.p.m. The conductances of the samples and the percentages of sodium (alkali bases) were low in each instance, and in all samples the sums of chloride and sulphate were less than the bicarbonate.

QUADRANGLES 5 TO 13

The San Joaquin Valley waters grouped for consideration in quadrangles 5 to 13 include those along the valley axis and those to the east and to the west of the valley axis northwestward from Herndon and Firebaugh to the Mount Diablo base line.

Samples, either from streams or wells, collected east of the lowlands adjacent to the San Joaquin River carried little mineral matter. Poyner Spring, which is 7 miles northeast of Manteca, had a conductance of 63.5, and the conductances of all others were less than 45. Evidences of boron injury were nowhere observed in this area east of the valley axis, and with the exception of Poyner Spring, which had 0.40 p.p.m. of boron, none of the waters sampled contained more than 0.15 p.p.m. Bicarbonate concentrations in all samples exceeded chloride concentrations and were usually 3 to 4 times as high. Chloride concentrations in all samples exceeded sulphate concentrations and were usually much higher than the sulphate. Calcium concentrations in all instances exceeded magnesium concentrations. Sodium constituted less than 50 percent of the bases in all except Poyner Spring and one other source with a very low conductance.

The ground waters west of the San Joaquin River are highly variable in quality but as a class are clearly differentiated from the ground waters east of the river. Few ground waters west of the river, as represented by 53 samples, had conductances less than 50, and many had conductances greater than 100. Conductances less than 50 were obtained only in the instances of two drainage wells near Dos Palos and a well in Los Banos. A considerable number of these groundwater samples contained less than 0.5 p.p.m. of boron, but only in four drainage wells, a shallow domestic well, and the flowing well on the Durham farm, all near Dos Palos, did any of the samples contain less than 0.25 p.p.m. of boron. Numerous samples contained in excess of 2 p.p.m. of boron.

Sulphate was present in appreciable concentrations in nearly all of the wells sampled west of the river, but only a few more than half of the samples contained higher concentrations of sulphate than of chloride. Bicarbonate concentrations commonly exceeded the chloride and sulphate concentrations.

In this portion of the west side of the valley the concentration of sodium was in most instances less than the sum of the calcium and magnesium concentrations, but there were a number of marked exceptions. In approximately one-third of the samples the magnesium concentrations exceeded the calcium concentrations.

Something of the character of the ground waters along the axis of the valley to the east of the San Joaquin River but closer to the river than those discussed is illustrated in part by samples at locations 1 and 5 of quadrangle 6, location 14 of quadrangle 7, and locations 3, 8, 9, 10, and 12 of quadrangle 9. None of the wells west of the river are included as axial waters, but some of them might properly be considered as such. In this central area there were at one time

many flowing wells, and some of those here represented still flow. The samples are too few in number to permit of generalizations, but it is indicated that boron may occur to the extent of 2 or more p.p.m. in waters at depths of several hundred feet, and that such waters may be saline; but one sample from a flowing well 265 feet deep carried only 0.07 p.p.m. of boron and had a conductance below 50. Two shallow wells near Stevinson had little boron and were not saline.

QUADRANGLE 5

(Tps. 1, 2, 3, and 4 S., Rs. 1, 2, and 3 E.)

The upper ground water in the vicinity of Byron, location 1, insofar as it may be represented by the shallow well at the depot, is like that from the wells in the vicinity of Brentwood, quadrangle 2.

At Byron Hot Springs only one of the several springs was sampled. Analyses from other sources have shown the water from certain of these springs to possess distinctly different characteristics. The "white sulphur spring" is characterized by free hydrogen sulphide gas, a temperature of 90° F., and high concentrations of boron, bicarbonate, chloride, and alkali bases.

Two samples, locations 3 and 4, were obtained near Altamont. The first of these is from the Southern Pacific Railroad well in the creek bottom about one-half mile southwest of the depot. It carries sufficient boron, 1.90 p.p.m., to produce marked symptoms on all the plantings in the station park. These plants receive excellent care and many of them make a good showing notwithstanding boron injury. The second sample from Altamont, location 4, is of water produced by an abandoned oil well. This water, which is unsuited for gardens or other agricultural use, had 20.1 p.p.m. of boron and only a trace of sulphate.

The samples from Pleasanton, Livermore, and Alameda Creek, locations 5, 6, and 7, are not related to the San Joaquin Valley except as they are derived from the coastal mountains. All are low in conductance, boron, chloride, and alkali bases.

QUADRANGLE 6

(Tps. 1, 2, 3, and 4 S., Rs. 4, 5, and 6 E.)

The Lathrop sample, location 1, had the lowest conductance, boron, and sulphate content of the wells sampled in quadrangle 6, and this relatively shallow well is east of the San Joaquin River. The water was much like those sampled in quadrangle 7 to the east. The California Irrigated Farms well at location 5, also east of the river, drilled to 654 feet and perforated only below 618 feet, had a conductance of 89.8, carried 0.82 p.p.m. of boron, and sodium constituted 64 percent of the bases.

Two relatively poor waters are represented by the samples from foothill wells at locations 2 and 9. The first was from the now abandoned Fabian flowing well, which was drilled to a depth of about 2,000 feet, presumably in search of oil. This warm and highly mineralized water had 5.52 p.p.m. of boron and a conductance of 380. The second sample mentioned was from a brick-cased well with a static level at about 12 feet beside Mountainhouse Creek; this water, which is used at an automobile service station, doubtless represents creek underflow. It had a conductance of 206 and a boron concentration of 3.02 p.p.m.

The five wells sampled between the foothills and the San Joaquin River, locations 3, 4, 6, 7, and 8, all produced water higher in sulphates than in chlorides, with the concentration of alkali bases less than the sum of calcium and magnesium. In four of the wells the boron concentrations were sufficiently high to affect boron-sensitive plants.

QUADRANGLE 7

(Tps. 1, 2, 3, and 4 S., Rs. 4, 5, and 6 E.)

Of the 7 scattered samples collected east of the San Joaquin River, those at locations 1, 2, 3, 4, and 7 all had conductances less than 45, boron concentrations below 0.15 p.p.m., and sulphate concentrations of 0.35 milligram equivalents or less. The percentages of sodium (alkali bases) were less than 40. The well at location 14 in comparatively low land near the river had a conductance of 88.1, 0.27 p.p.m. of boron, and 66 percent of alkali bases. The Poyner Spring, location 15, long used as a watering place for stock, had more boron (0.40 p.p.m.) than has been found elsewhere in the lower portion of the valley so far east of the valley axis. In all of these samples the salinity was low, and in each bicarbonates exceeded chlorides and chlorides exceeded sulphates.

Six wells were sampled west of the San Joaquin River. In two of these, locations 9 and 11, the boron concentrations exceeded 3.00 p.p.m., and both were relatively saline. The other four, locations 6, 8, 10, and 13, did not carry injurious concentrations of salt, and the boron concentrations ranged from 0.53 to 1.25 p.p.m. In all of the 6 wells the sum of calcium and magnesium exceeded sodium, and sulphates exceeded chlorides.

In a portion of this quadrangle west of the river there are a number of small areas of unproductive land such as is illustrated in figure 1 (p. 22). Soils from these places have shown abnormally high concentrations of boron, and orchard plantings made in them have either died or remained unthrifty, with the development of marked boron symptoms. It had been concluded that the boron in these spots was of local origin, since the land was irrigated with San Joaquin River water. In a healthy vineyard where no evidence of boron injury had previously been observed, a few groups of vines made little new growth in the spring of 1932 and developed outstanding evidence of boron injury. The upper ground-water table in the area lies at depths of from 5 to 12 feet and in the winter of 1932 showed a tendency to rise. A sample was taken from the water table immediately below one of these injured vines in June and was found to contain 25.6 p.p.m. of boron, whereas 2 years previously a similar sample from a healthy vineyard across the roadway had contained but 0.5 p.p.m. of boron. It is assumed that underlying water had been in contact either with soils very high in boron or with soluble boron minerals, and that this underlying water had been forced upward into the root zone of the grapes as a result of an increase in its hydrostatic pressure. This interpretation may also provide an explanation for the occurrence of boron in the older spots discussed.

Under location 5 (table 15) there are given a series of analyses of samples collected from the San Joaquin River at the El Solyo Ranch diversion below the mouth of the Tuolumne. In the table footnote the corresponding river discharges are reported. As represented by

these determinations the quality of the San Joaquin River at this point is different from its quality at Mendota, quadrangle 15, location 5. During parts of the year most of the river flow is from the Tuolumne and the remainder represents return flow to the San Joaquin from drainage. On August 1, 1931, the river discharge at the El Solyo diversion was 135 cubic feet per second and above the mouth of the Tuolumne, location 12, the discharge was 35 cubic feet per second. The latter water, from Lairds Slough, was twice as saline as that at the El Solyo diversion and 25 times as saline as that of the river at Mendota. It is to be observed that none of the 16 samples from the San Joaquin River at the El Solyo diversion, location 5, had conductances above 80, and that the concentrations of boron, chloride, and sulphate and the percentages of sodium were well within the limits of safety.

Samples of grape leaves collected west of the river in this quadrangle varied from 45 to 754 p.p.m. in their boron content. Those showing injury either were irrigated by well waters high in boron or were collected from the areas of boron-contaminated soils. Other than in localized areas such as have been mentioned, plantings irrigated by San Joaquin River water have not shown evidence of boron injury.

QUADRANGLE 8

(Tps. 5, 6, 7, and 8 S., Rs. 7, 8, and 9 E.)

The greater part of quadrangle 8 lies west of the San Joaquin River, and nearly all of the wells sampled were moderately saline but with a few exceptions not injuriously so. The boron concentrations in the wells ranged from 0.26 to 1.08 p.p.m.; in 6 of the 12 samples chlorides exceeded sulphates, and in 3 the concentration of sodium exceeded the sum of calcium and magnesium.

Boron symptoms were evident here and there in this area, and in the southeast portion these symptoms appeared to be related, in part at least, to the quality of the subsoil water, which in some places is high. Particularly were boron symptoms outstanding in Gustine, where the new municipal well had only 0.46 p.p.m. of boron; but this well had recently replaced an older well, a sample of which could not be obtained. The water table in Gustine is normally high, and at the time of the sample it was reported as being about 4 feet below the soil surface.

Three samples of walnut leaves showing evidence of moderate boron injury were collected in the vicinity of Gustine on October 8, 1929. One of them (no. 307) was from an old grove in the southeast corner of sec. 36, T. 8, R. 9 E. These leaves contained 628 p.p.m. of boron. The trees were large and previous to 1928 had been irrigated with water diverted from the San Joaquin River. Subsequently the grove was unirrigated. The ground water was reported as being at about 5 feet. The second sample of walnut leaves (no. 308) was taken from the grove irrigated by the well at location 9; this sample contained 400 p.p.m. of boron; the trees were from 4 to 6 years old. The third sample (no. 310) was from trees in a grove of the same age immediately to the south but irrigated from the Outside Canal. This leaf sample contained 379 p.p.m. of boron, and the water table was reported as varying between 7 and 14 feet. An adjacent canal-irrigated old grove, likewise showing some evidence of mild boron injury, was reported as producing about 1 ton of walnuts per acre per year.

Canals diverting water from the San Joaquin River at and below Mendota supply irrigation water as far north as Crows Landing, but in the upper portion of the area served, ample supplies of water are not always available.

The San Joaquin River at Mendota carries remarkably pure water; it is very low in total salinity even as late as October, and the concentration of boron is negligible. (See analyses under locations 5 and 6, quadrangle 15, table 23.) The greater part and at times all of the river water is diverted at Mendota to canals supplying lands west of the river. During the late summer the water carried by the San Joaquin above the mouth of the Tuolumne is largely if not entirely return flow from irrigated lands. A comparison of the difference in the return flow water and the river water at Mendota is afforded by the samples at Mendota of October 1929, which had conductances of less than 6, and by the sample of October 1930 of the river as diverted at Patterson, location 12, which had a conductance of 84.8.

QUADRANGLE 9

(Tps. 5, 6, 7, and 8 S., Rs. 10, 11, and 12 E.)

Two classes of water are represented by the samples in quadrangle 9. The four flowing, or formerly flowing, deep wells at locations 2, 3, and 8, near the Merced River north of Stevinson, had conductances of 273, 234, 270, and 440, relatively high concentrations of chlorides, and in two at least high concentrations of boron. In each sodium was the predominating base. In the first two of these wells sulphates were abundant, while in the latter, which had 35 milligram equivalents of chloride, there was little sulphate. The sample from the old flowing well at the Charles Lyon Gun Club, location 10, had a high percentage of sodium, but the conductance of this water was but 47.6, and boron was present only to the extent of 0.07 p.p.m., clearly indicating an origin quite distinct from the other deep waters.

The examples of the water from shallower wells (locations 1, 4, 7, 9, and 11) and the surface waters from the Merced River (location 6) and from the canal at Delhi (location 5) are all of excellent quality, typical of the drainage from the Sierra Nevada.

Leaf samples of walnut and peach, collected June 22, 1929, in the Delhi settlement adjacent to location 4, had respectively 47 and 32 p.p.m. of boron.

QUADRANGLE 10

(Tps. 9, 10, 11, and 12 S., Rs. 7, 8, and 9 E.)

The deeper water underlying that portion of quadrangle 10 within the valley is represented by samples from flowing wells at locations 1 and 3 about 6 miles respectively southwest and southeast of Gustine. These samples had conductances of 515 and 202 and boron concentrations of 2.74 and 1.99 p.p.m., respectively. The first, the Allen Ranch stock well, located near the mouth of an arroyo, is remarkably high in magnesium and sodium sulphates, whereas water from the new well of the Salinas Gun Club, 7 miles east in the valley floor, carried more chloride but less than one-eighth as much sulphate. The water of a third deep flowing well between Los Banos and Dos Palos, quadrangle 11, location 7, did not resemble either of these.

San Luis Creek, sampled at location 5, presumably has made a material contribution to the subsurface waters of its delta, and the proportion of ions in the well at Santa Nella, location 6, is similar,

though the concentrations of all ions excepting calcium and bicarbonate are materially higher. The samples collected at locations 2 and 4 to the north did not resemble that collected at 6 and were different one from the other.

QUADRANGLE 11

(Tps. 9, 10, 11, and 12 S., Rs. 10, 11, and 12 E.)

Samples from locations 1 and 2 are of shallow domestic wells in and near Los Banos. Under both wells, as is the case elsewhere here and there in the vicinity of Los Banos, typical boron symptoms were in evidence; these waters carried 1.13 and 0.65 p.p.m. of boron respectively. Sample 2774 at location 12 is from a shallow well in the vicinity of Dos Palos; the boron concentration was 0.18 p.p.m., and there was no evidence of boron injury.

The drainage wells at locations 6, 7, 10, 11, and 13 are all adjacent to irrigation canals and most of them had been operated for a sufficient time to lower the water table in their vicinity. The water produced by these wells is markedly variable in total concentration and in the proportions of the different ions; in all, the concentration of boron was insufficient to be considered agriculturally significant.

Samples at 8, 14, 15, and 16 are ground waters from wells on land adjacent to the foothills above irrigation canals south of Los Banos and Dos Palos. Independent of other characteristics, the boron concentrations were too high for use in the production of other than boron-tolerant crops. In each the concentrations of chloride or sulphate or both were high, and the percentage of sodium in each was sufficiently high to raise a question as to the effect of prolonged use of these waters on the physical character of the soil.

Sample 2871, location 9, was bailed from a 500-foot hole drilled to supply irrigation water. A pump was never installed in this well, and the concentrations of boron, chlorides, and sulphates were the highest encountered in well waters during the investigations. The chloride concentration was 63 percent as high as sea water and the sodium (alkali bases) concentration exceeded that of sea water by 1.9 times.

QUADRANGLE 12

(Tps. 9, 10, 11, and 12 S., Rs. 13, 14, and 15 E. Quadrangle map not shown.)

The flat area east of the San Joaquin River embraced by quadrangle 12 is not cultivated extensively. Some water from the river is used for irrigation both east and west of Firebaugh, but a large part of the bottom lands east of the river are grazed.

The concentrations of chlorides and sulphates in the deep well sampled west of the river, location 2, in common with many of the wells in quadrangle 15 to the south, are relatively high, and as in many of those wells, sodium is the predominant base, but as compared with the quadrangle 15 wells the boron content of this well, 0.47 p.p.m., is relatively low. The relatively good water represented by the sample from location 1 is from the old flowing well on the Durham farm east of Dos Palos.

QUADRANGLE 13

(Tps. 9, 10, 11, and 12 S., Rs. 16, 17, and 18 E. Quadrangle map not shown.)

The 3 samples in quadrangle 13 together with the 1 from Merced and 2 from sec. 6, T. 8 S., R. 16 E., are believed to be typical of the

ground waters in this east-side area. All are of low salinity, have little boron, the chlorides exceed the sulphates, and the alkaline earth bases exceed the alkali bases.

QUADRANGLES 14 TO 26

The area embraced by the group of quadrangles numbered from 14 to 26 includes that portion of the San Joaquin Valley southward from Herndon and Firebaugh to the northern boundary of Kern County. The bed of Tulare Lake is situated in the center of the southern portion of this area and has in the past overflowed through Kings River Slough to the San Joaquin River near Mendota. The Kings River water which reaches the axis of the valley normally discharges into the slough, which likewise receives some water backed up by the dam across the San Joaquin River at Mendota. At times of excessive run-off the Kings River discharges into Tulare Lake through canals constructed to carry the water to a portion of the lake bed surrounded by levees. These levees and canals were constructed to protect the farm lands of the lake bed from flood waters.

The ground waters east of the broad low-lying area adjacent to Kings River Slough and Tulare Lake are for the most part of excellent quality and similar in general character to those encountered east and north of the San Joaquin River. Only one of the few scattered samples collected in quadrangles 17, 21, and 26 was saline, and similarly good waters are represented by some of the samples in quadrangles 16, 20, and 25. The concentration of boron in certain of these samples was remarkably low. As in the area east of the San Joaquin River to the north, the bicarbonate concentrations tended to be materially higher than the chloride concentrations and the chloride concentrations higher than sulphate. In some samples sodium constituted in excess of 50 percent of the bases, but where the conductances were in the order of 25 or less the percentage of sodium is of only secondary significance.

The surface and ground waters in the area west of the central or axial portion of this section of the valley tend to be saline and to contain sufficient boron to constitute a factor of agricultural consequence. The conductances of the samples obtained were in nearly all instances in excess of 100, with conductances above 250 quite common. The boron concentration in one of the water samples was as low as 0.20 p.p.m., but concentrations of 1 part per million or more were common to the greater number of the samples; though in quadrangle 23, which includes Kettleman Hills and drainage from mountains and foothills to the west, only 1 of 10 samples contained as much as 1 p.p.m.

The bicarbonate concentrations in these waters west of the valley axis were mostly higher than in the waters east of the valley axis but were usually exceeded by either chloride or sulphate. In this area as a whole nearly 80 percent of the waters carried more sulphate than chloride. Nearly all of them carried substantial quantities of calcium and magnesium, but in considerably over half of the samples the sum of calcium and magnesium was exceeded by sodium.

The ground waters of the central or axial portion of the valley are of such character and variability that the analyses lend themselves better to detailed study than to generalization. These waters nevertheless tended to have higher conductances and higher boron concen-

trations than were found in representative samples east of the valley axis. In some of the axial waters the sulphate concentrations were particularly low, and in these there was marked tendency toward high sodium percentages.

QUADRANGLE 14

(Tps. 13, 14, 15, and 16 S., Rs. 10, 11, and 12 E.)

Sample 2770, location 1, was taken from one of a number of almost stagnant pools along the then mostly dry bed of Little Panoche Creek below Mercy School. It contained 18.60 p.p.m. of boron, and the conductance and sodium concentrations were both high. Unlike the Mercy Springs water, location 3, with 13.0 p.p.m. of boron and little else than sodium chloride, the creek sample was high in sulphate, calcium, and magnesium. Plantings watered from a farm well above Mercy School showed marked boron symptoms.

The irrigation well at location 2, 6 miles east and a little north of where Little Panoche Creek wash leaves the foothills, produces water very unlike the creek sample; but wells at locations 14 and 15 of quadrangle 11, 6 miles north and 1 and 3 miles east of the wash, produce water less saline but having a proportion of ions and a salinity which suggest that Little Panoche Creek run-off has there contributed to the ground water. The salinity of Little Panoche Creek as sampled is unquestionably higher than would be the case during run-off after rains.

Panoche Creek and Silver Creek, its tributary, were sampled in May 1930 and again in September 1931. The Panoche Creek samples, location 5, were taken about 5 miles above the junction with Silver Creek. The Panoche Creek samples had conductances of 279 and 289, whereas those of Silver Creek were 806 and 927. The boron concentrations in each were high, but Panoche Creek with 4.89 and 6.52 p.p.m. had only about half as much as Silver Creek with 8.78 and 12.7 p.p.m. In each the alkali base content was approximately equivalent to the sum of calcium and magnesium.

Panoche Creek underflow above Griswold Creek may be represented by the well sample at location 4, and Griswold Creek underflow is probably represented by the sample from a well at location 7. If this is the case, a major portion of the boron and a major portion of the salinity represented in Panoche Creek is derived respectively from Silver and Griswold Creeks. The conductance of the water at location 4 was 129, and that from location 7 was 618. The corresponding boron concentrations were 1.54 and 7.44.

QUADRANGLE 15

(Tps. 13, 14, 15, and 16 S., Rs. 13, 14, and 15 E.)

High prices for cereals and cotton were immediately responsible for the deep-well agricultural development in the Panoche Creek delta area southwest of Mendota, though some of the acreage is devoted to other crops such as grapes, figs, and asparagus. Wells with discharges up to 3 cubic feet per second were drilled to depths of 1,400 feet to tap water-bearing sands interspersed with blue clay below 600 feet. Water-bearing sands occur at high levels, but the casings were not ordinarily perforated for them, as the upper water was known to be more saline. Under certain cropping systems individual wells in this area serve a section of land.

The irrigation waters used in this quadrangle are in many instances saline. The conductances of the well samples collected ranged from 127 to 580, corresponding with total solids of from 900 to 3,800 p.p.m. The boron concentrations in the same samples varied from 0.91 to 2.99 p.p.m., the average being 1.55; sodium (alkali bases) constituted from 42 to 93 percent of the total bases; chlorides varied from 1.30 to 44.50 m.e.; and sulphates, which tended to be of more uniform concentration, varied from 7.69 to an outstanding concentration in the Chaney Ranch well of 30.40 m.e. Chlorides exceeded sulphates in 6 of the 16 samples, but in no instances were sulphates low.

General indications of a directional trend in the characteristics of the water produced by the wells in the Panoche Creek delta are lacking. Wells at locations 1, 3, 8, and 9 were all high in chlorides, and these wells are in the northwest portion of the area sampled; but the well at location 4, which is adjacent to those at 8 and 9, was low in chlorides. The well at location 12 was highest of all in chlorides, and it is adjacent to wells at 11 and 15, which were low in chlorides.

The water from the Chaney Ranch well, location 18, had a higher proportion of calcium and magnesium and higher concentration of sulphate than the wells farther out on the delta, and in these respects it is not unlike that of Panoche Creek with the contribution made by Silver Creek taken into account. As judged by the quality of water, it seems improbable that Panoche Creek has made a material contribution, however, to the deeper water-bearing strata underlying the lower part of the delta fan. The surface elevation at the Chaney Ranch is 140 feet higher than that at the nearest of the wells of the lower group, and the Chaney Ranch well was drilled to but 1,000 feet, whereas the wells farther out on the delta were drilled to 1,400 feet and the casings perforated only below 600 feet.

The uniform depths of wells and depths of perforation and the evenness of the delta-plain topography cause the variability shown in the quality of water obtained from these deep wells to become noteworthy. With the lower 800 feet of the well casings perforated, waters from many strata must contribute to the discharge of each. It is to be assumed that the water-bearing strata tapped are in the form of lenses, or uneven and limited layers of successively deposited permeable material. To explain the variation in the quality of water of neighboring wells it appears necessary to assume that there is now little movement in this ground water, and that the water of different strata has come in during different periods, with associated though unknown variations in source.

The waters from many of these wells are not suited to permanent agriculture, and the agricultural experience of the area bears out experience with such waters elsewhere. A number of the operators have recognized that the fertility of this initially productive land is of short duration when the waters from certain wells are used, and that such profit as was to be obtained must be derived during the first few years of cultivation. The profitable utilization of waters from such wells as those at locations 4, 9, 10, and possibly 15 and 19, however, might extend over many years, particularly if gypsum or sulphur is used to offset the effects of the high percentages of sodium.

The analyses reported under locations 5, 6, and 17 are of samples from the San Joaquin River, which, in contrast with the well waters of this quadrangle, is remarkably pure. The location 5 sample, with a

conductance of 5.55, was from the river below the Mendota Dam; the location 6 sample, with a conductance of 5.29, was from Columbia Canal as diverted several miles up stream; and the location 17 sample, with a conductance of 9.93, was from Fresno Slough at White's Bridge. These same samples contained respectively 0.07, 0.11, and 0.02 p.p.m. of boron.

QUADRANGLE 16

(Tps. 13, 14, 15, and 16 S., Rs. 16, 17, and 18 E.)

The eight samples collected along the axis of the valley in the southwest portion of quadrangle 16, locations 4, 5, 6, 8, 9, and 10, were from wells that were relatively deep; the well in San Joaquin, believed to be the deepest, was reported as having been drilled to 1,700 feet. The waters produced by these wells had, with one exception, about 1 p.p.m. of boron. None of them contained injurious concentrations of either chloride or sulphate, but all were sufficiently high in percentage of sodium to render them unsatisfactory for prolonged agricultural use. The conductances of these wells varied between 58.5 and 125.

Water of very different character is produced by a series of some 21 wells discharging into a James Irrigation District canal extending to the northeast at a right angle with the valley axis. This canal and the series of wells, spaced about three to a mile, extends diagonally across T. 15 S., R. 18 E. These wells have depths of 214 to 300 feet. The water produced by them, as represented by a composite sample taken from the canal at location 7 at a time when most of the wells were operating, had a conductance of only 28.9, contained but 0.03 p.p.m. of boron, and sodium constituted but 27 percent of the bases.

Two wells were sampled at Jameson. The shallow well at the Southern Pacific Railroad section house, location 1, produced water low in mineral matter and boron, whereas two samples from the 600-foot well supplying water for the boilers of the Associated Pipe Line Co., location 2, had conductances of 376 and 281 and were unusually high in sodium chloride. Sodium constituted 90 percent of the bases, and there was in excess of 1 p.p.m. of boron.

The water from the 70-foot well at location 3, east of Jameson, was very similar to that produced by the series of wells along the canal.

QUADRANGLE 17

(Tps. 13, 14, 15, and 16 S., Rs. 19, 20, and 21 E.)

The well waters sampled in quadrangle 17 are believed to be generally representative of the area, and they are noteworthy for their low concentrations of salt; none of the wells had conductances above 50, and in none did the boron concentration exceed 0.10 p.p.m. In most of the well samples calcium was the predominating base, and in all the percentage of sodium was less than 50. The San Joaquin River near Herndon carried sodium to the extent of 58 percent of its bases, but this has little or no significance, since the water had a conductance of but 5.9.

Ground waters with as little boron as is represented in these wells at least suggest that the boron concentrations in the soil solutions may likewise be low. It is not improbable that boron might be beneficially applied here and there in the area as a fertilizer for crops having high-

boron requirements. Such crops as beets, cotton, grapes, and asparagus would be most apt to show response.

QUADRANGLE 18

(Tps. 17, 18, 19, and 20 S., Rs. 13, 14, and 15 E.)

The sample at location 2 from the Fresno Hot Springs, 10 miles west of Coalinga, was not highly mineralized. It had a conductance of 64.2, the principal salt being sodium bicarbonate, and relative to numerous well samples the concentration of this was low. The concentration of boron, 7.76 p.p.m., was relatively high, as is the case in many hot springs.

Sample 2756, location 1, at the Halfway Station of the Associated Pipe Line north of Cantua Creek, may or may not reflect Cantua Creek run-off or underflow. The well is drilled to 700 feet, and the static level was 295 feet below the surface. The conductance was 178; the boron concentration (0.60 p.p.m.) was not as high as in wells in the quadrangle to the east, and the percentage of sodium is much lower. This water, which is fairly high in magnesium sulphate, is not used for drinking. The shallow well at location 3, with a conductance of 208 and 1.68 p.p.m. of boron, probably represents Los Gatos Creek underflow.

The two deep wells in Coalinga, location 4, were both drilled to 1,400 feet; the casing of the first (sample 2752) is perforated below 250 feet, whereas the casing of the second (sample 2753) is not perforated. If it is assumed that the deeper waters tapped by each are alike, then the upper strata waters must be low in bicarbonate and magnesium and high in chloride and sodium, with the boron, sulphate, and calcium concentrations substantially the same in both the upper and lower strata. Coalinga drinking water is brought in from elsewhere.

QUADRANGLE 19

(Tps. 17, 18, 19, and 20 S., Rs. 16, 17, and 18 E.)

The major portion of the irrigation water utilized in quadrangle 19 is obtained from relatively deep wells. Nine wells with depths of 800 feet or more were sampled, and these waters, with some exceptions, had conductances of about 100, boron concentrations of about 1 p.p.m., and sodium percentages between 70 and 90. The ranges for all nine of these wells were: Conductances from 87 to 182, boron concentrations from 0.39 to 1.74 p.p.m., and sodium percentages between 54 and 90. The waters from wells with depths of less than 800 feet were more diverse. Those sampled had conductances between 58 and 433, boron concentrations between 0.08 and 1.63 p.p.m., and sodium percentages between 34 and 91.

In some instances boron was believed to be present in significant concentrations as a natural constituent of the soil, and under certain of the wells evidence of injury to the more sensitive plants was marked. Under the well at location 13, boron symptoms were pronounced, and grape leaves collected in September 1929 contained 1,019 p.p.m. of boron.

The general tendency toward high percentages of sodium in the deeper waters of this quadrangle deserves perhaps more serious consideration in the culture of semitolerant or tolerant crops than the boron concentrations. As an illustration of the importance of

the sodium percentage, the shallow well at location 7 produces water with a conductance of 330, and yet it has been used for 15 years without indications of declining yields or tightening of the soil. The sulphate concentration of this water was 31.23 m.e., but the concentration of calcium and magnesium together was approximately twice as great as the sodium concentration. Nearby soils irrigated with water with a similar concentration of sodium but with very little calcium and magnesium have become hard, and alfalfa has been abandoned after 9 years. Where upper-strata waters are high in calcium and magnesium and low in sodium in this area, owners should give consideration to the possibility of decreasing the percentage of sodium by perforating deep-well casings to admit water from the upper strata. The water from the location 7 well carried calcium and magnesium in excess of sodium equivalent to 3,238 pounds of gypsum per acre-foot of water.

At location 10, sample 4846, water from a stratum at 70 feet, while high in calcium and magnesium (12.37 and 16.71 milligram equivalents respectively), was also proportionately high in sodium (27.39 milligram equivalents). At this location a 650-foot well perforated below 170 feet produced water (sample 4844) with a conductance of 247 and a sodium percentage of 43. Such water, while not highly satisfactory, would nevertheless be preferred over a long period to a water such as that from location 11, or possibly from 3 or 8; and certainly it would give better results than the water from the well at location 9, the casings of which are perforated only below 900 feet.

QUADRANGLE 20

(Tps. 17, 18, 19, and 20 S., Rs. 19, 20, and 21 E.)

Sodium was the predominating base in all samples from wells in quadrangle 20 that had depths of 195 feet or more (locations 1, 2, 3, 6, 7, 8, 9, 10, 11, and 12). The boron concentrations in the same wells were variable; three of them had more than 1 p.p.m. of boron, and three located in Hanford had less than 0.5 p.p.m.

The water from the three deep wells near Stratford (locations 10, 11, and 12) differed from the other waters sampled in this quadrangle in that the conductances exceeded 100 and the sulphate materially exceeded the chloride.

The Kings River water, as sampled from a canal near Lemoore (location 4), carried very little salt, and similar water was obtained from the 120-foot well on the Lucern Vineyard property 4 miles northwest of Hanford at location 5.

QUADRANGLE 21

(Tps. 17, 18, 19, and 20 S., Rs. 22, 23, and 24 E.)

A number of the ground waters sampled in quadrangle 21 had high percentages of sodium, but only one was saline. The saline water was from a 100-foot well 6 miles north of Corcoran at location 6. A second well on the same property, location 4, drilled to 2,100 feet, produced water with a conductance of 35.1. The latter water is not unlike the Hanford waters, one of which is represented by the sample at location 2.

Kings River, here represented by two samples at location 1 and in quadrangle 20 by a canal sample at location 4, was found to have a

conductance below 15 and very little boron on each of the three sampling dates.

QUADRANGLE 22

(Tps. 21, 22, 23, and 24 S., Rs. 13, 14, and 15 E. Quadrangle map not shown.)

The two samples collected in quadrangle 22, locations 1 and 2, are from shallow wells adjacent respectively to Waltham and Jacelitos Creeks. The conductances were 506 and 278 and the boron concentrations 4.29 and 0.80 respectively. Both were sulphate waters; the first, with 41.36 m.e. of sulphate, had 41.18 m.e. of alkaline bases.

QUADRANGLE 23

(Tps 21, 22, 23, and 24 S., Rs. 19, 20, and 21 E.)

A sample from the Dudley pump-station well west of Kettleman Hills in the southeastern portion of the quadrangle, location 10, had 1.28 p.p.m. of boron. None of the other 9 well samples contained more than 0.66 p.p.m. of boron. The conductances of all the samples west of Kettleman Hills were relatively high, but in none did sodium constitute more than 47 percent of the bases. In each of these waters the sulphate concentration exceeded that of any other ion.

The group of three irrigation wells northeast of Kettleman Hills, locations 3, 4, and 5, produced water of much lower salinity than the waters more closely associated with coast range drainage as sampled to the west and south of these hills, but the percentages of sodium were 72, 58, and 64, respectively. A tendency for the soils irrigated to become hard was in evidence. Grapes, plums, walnuts, pears, apricots, melons, and cottonwoods all showed typical boron injury under the location 3 well. Walnut and orange leaves collected September 25, 1929, under a well on the corner west of the location 5 well, carried, respectively, 597 and 431 p.p.m. of boron, and fig leaves under the location 5 well contained 767 p.p.m. of boron. Though these concentrations are not particularly high, they afford indications of appreciable concentrations of boron in the soils upon which the trees were grown. It is probable that at least some of this boron is present as a natural constituent of the soil, since none of the three waters contained more than 0.40 p.p.m.

QUADRANGLE 24

(Tps. 21, 22, 23, and 24 S., Rs., 19, 20, and 21 E.)

The Tulare Lake bed is now dry and farmed extensively, but lake waters at one time or another in the past not only occupied a considerable part of this quadrangle but extended into portions of quadrangles 20, 21, 25, 27, and 28. The lake bottom has an elevation of 180 feet above sea level, and it was only at an elevation of approximately 220 feet that an outlet became available through Kings River Slough to the San Joaquin River. The margin shown, as of 1884, corresponds to an elevation of about 194 feet. The available records on lake levels have been summarized by Dole (*27*), and according to his summary the lake previous to 1884 had not been recorded as being below 192 feet as far back as 1853; but the general impression exists that the lake has probably been recurrently filled and dried out in the past; this view, the writer is informed, is supported by Indian legends.

The irrigation wells known to the writer in the old Tulare Lake bed within the 1884 margin are deep. The depths of the wells sampled

ranged from 1,400 to 2,100 feet. One shallow well, location 18, not used for irrigation, was also sampled. In drilling these deep wells many successive strata of heavy clay are reported to have been encountered, the occurrence of which permits a question as to whether these deep waters, in some instances not highly mineralized, have been derived or replenished from the lake during periods when the lake has been filled, or whether the source has been more remote in time or place. This question naturally is not peculiar to the deep-well waters underlying the lake bed, since the time and place of origin of the deeper waters of the valley floor as a whole are uncertain. The waters underlying the lake bed are nevertheless subject to special consideration for the reason that they have been found to be uniformly low in their sulphate content for fresh water of such salinity. Of the 17 deep wells sampled, only 2 contained as much as 0.40 m.e. per liter of sulphate, and 6 contained less than 0.01 m.e. Other deep-well waters to the north, south, and east were also examined and likewise found to contain very little sulphate and yet their total salinity was well above that of the fresh waters derived from the Sierra. As is discussed later in this bulletin, it is the writer's belief that the low sulphate concentrations of waters underlying this area reflect anaerobic bacterial reduction of sulphate.

Normal carbonates were not found in any of these waters; bicarbonate and chloride tended to be present in somewhat similar concentrations; and in all but one of the samples alkali bases exceeded calcium and magnesium. In these deep-well waters no boron concentration exceeded 1 p.p.m., and in one the concentration was as low as 0.20 p.p.m.

It is not believed that the boron concentrations occurring in most of these irrigation waters are sufficiently high to affect materially the cereals and cotton grown in the lake bed. Boron may occur naturally in a part of the lake bottom, and there is evidence in some sections that with continued irrigation and utilization of the land, yields have decreased, but this is not necessarily general. Where reduced yields occur in successive crops consideration should be given to the abundance with which the irrigation water is used.

Boron determinations seem never to have been a part of the early Tulare Lake water analyses, but it is nevertheless not improbable that it may have been an important constituent, particularly at low stages. The subsoil at variable depths is probably impregnated with the salts residual to the evaporated lake waters. Various plants under the well at location 14, which had 0.49 p.p.m. of boron, showed symptoms of mild boron injury; leaves of string bean (sample no. 298) contained 247 p.p.m. of boron, and leaves of cottonwood 657 p.p.m. when sampled September 25, 1929. Three samples of milo leaves (nos. 739, 740, and 741) collected August 29, 1930, from different sections contained respectively 578, 1,040, and 144 p.p.m. of boron. The water used to irrigate the milo represented by samples 739 and 740 had slightly less than 0.5 p.p.m. of boron, and that used on sample 741 had 0.65 p.p.m. Samples 739 and 740 were from different sections of land cultivated respectively for 2 and 5 years.

Water from the shallow well at location 18 was unsuitable for agricultural use, and the upper waters in this region are generally recognized as being saline.

QUADRANGLE 25

(Tps. 21, 22, 23, and 24 S., Rs. 22, 23, and 24 E.)

The wells west of Angiola at locations 5 and 7 in quadrangle 25, with depths of 1,900 feet or more, are like the deep-well waters of the Tulare Lake bed in that they contain little sulphate and the predominating base is sodium. The wells at locations 6 and 8, also west of Angiola, are 470 and 460 feet deep; the former has 4.10 m.e. of sulphate and a higher conductance than any of the deep lake-bed wells.

Waters of low salinity and similar characteristics are obtained from the 400- and 460-foot Corcoran municipal wells (location 2) and the 350-foot Bryson Ranch irrigation well at Angiola (location 9). A shallow well just west of Corcoran (location 3) was saline and had 1.98 p.p.m. of boron, whereas a shallow well on the Bryson Ranch produced water of good quality. The canal sample at location 10, derived from wells near Smyrna, and the Alpaugh municipal water from 1,000-foot wells at location 11 are much like the Corcoran municipal and Bryson Ranch irrigation-well samples. All had low conductances, 35 or less; low boron concentration, 0.15 p.p.m. or less; low chlorides, and low sulphate concentrations. The alkali bases were twice as concentrated as the alkaline earth bases. Other than for the sodium percentages, all of these waters resemble those characteristic of the east side of the valley.

The wells at locations 12, 13, and 14 in T. 24 S., R. 22 E., about 14 miles north of Lost Hills, are, respectively, 825, 830, and 990 feet in depth; they are within a 2-mile radius, and the upper ground waters are excluded. All are very low in sulphate. The first-mentioned well is extremely saline, having a conductance of 1055, 85 m.e. of chloride, and 5.97 p.p.m. of boron. The other two wells each have less than 1 p.p.m. of boron and conductances below 100. The latter waters, like those from locations 5 and 7, are in the class of the deep Tulare Lake wells.

QUADRANGLE 26

(Tps. 21, 22, 23, and 24 S., Rs. 25, 26, and 27 E.)

The two samples collected in quadrangle 26 had 0.09 and 0.05 p.p.m. of boron, and boron symptoms have not been observed in the area. The well at Pixley, location 1, which formerly flowed, was drilled to a depth of 1,180 feet. The water had a conductance of 20.1 and contained little else than sodium bicarbonate. If sulphate was at one time present in the water tapped by this well it has now largely disappeared, as the sulphate concentration was 0.07 m.e.

The well at location 2, 2 miles north of Delano, serves a vineyard of Sultanina grapes on a light soil. Leaves collected from these grapes on September 20, 1929, contained 245 p.p.m. of boron. This concentration in grape leaves is greater than has resulted in cultures of Sultanina without added boron at the Rubidoux Laboratory, but less than the concentrations produced when solutions with 1 p.p.m. of boron have been applied.

QUADRANGLES 27 TO 35

The group of quadrangles numbered from 27 to 35 constitutes the southern portion of the San Joaquin Valley in Kern County. The greater part of the water available for irrigation is derived either

directly or indirectly from the Kern River. Caliente Creek makes a material contribution to the ground waters in the vicinity of Arvin, and some additional water is likewise contributed by small creeks and washes from the mountains enclosing the southern end of the valley on three sides; but in proportion to the supply afforded by the Kern River, all of these are of secondary importance. Kern River water is widely distributed by canals and some is stored in Buena Vista Lake Reservoir, from which lower-lying lands north of the lake are irrigated.

During cycles of wet years previous to the present extensive development of irrigation agriculture there has been at times a water connection between the Kern River and Tulare Lake; but water movement, either surface or underground, out of the southern portion of the valley is now believed to be negligible. Though Kern River water is relatively pure, it carries and has brought to the floor of the valley in the past an appreciable quantity of salt, and some is also brought into the valley by the creeks and washes referred to. The surface slope between Buena Vista and Tulare Lake bottoms averages less than 2 feet to the mile. Between Bakersfield and the depression marked by Kern Lake, Buena Vista Lake Reservoir, and Buena Vista Slough at the outer margin of the Kern River delta the slope is less than 5 feet per mile. There is a difference in elevation of only 13 feet between the Kern Lake depression, 15 miles south of Bakersfield, and Buttonwillow, 30 miles west of Bakersfield. In this low flat area and its northern extension there are fertile lands, but also there are many acres of nonproductive, unreclaimed, salt-impregnated waste land. In much of this land the water table is relatively near the surface.

Kern River water carries very little boron and little other mineral matter, and the wells sampled in the Kern River delta generally have been found to be of good quality. In the northern part of Kern County, wells sampled west of Buena Vista Slough were saline and high in boron. None of the wells sampled in the central part of the valley had more than 0.50 p.p.m. of boron and the deep wells relatively little mineral matter, but the percentages of sodium were high. Wells sampled in the eastern part of the area in or near Delano, Wasco, Shafter, and Famosa produced good agricultural water. The underground water situation near Lerdo is complex; certain of the deeper wells carry very little boron or other mineral matter, but the wells less than 500 feet in depth are sometimes both saline and high in boron. The waters below Caliente Creek in the Arvin section are mostly good, but there is an important area of boron contamination near the Rock Pile School. High concentrations of boron were found in a perched water table east of Caliente Wash. The water of Grapevine and San Emigdio Creeks had in the order of 1 p.p.m. of boron.

QUADRANGLE 27

(Tps. 25, 26, 27, and 28 S., Rs. 19, 20, and 21 E.)

There is almost no agriculture and there are very few wells in quadrangle 27, which lies to the west of Lost Hills. The static water levels in the four wells sampled, locations 1, 2, 3, and 4, were at depths of approximately 120, 357, 260, and 300 feet, respectively. Each of the four waters was highly saline, the conductances ranging from 363 to 610; each carried appreciable concentrations of boron, 1.15 to 5.23

p.p.m.; in each the sulphates exceeded the chlorides, but in all the chloride concentrations were high; each of the waters was hard, being high both in calcium and magnesium, but in each the sodium (alkali base) concentration was equal to or higher than the sum of calcium and magnesium. None of these waters would be suitable for agriculture.

QUADRANGLE 28

(Tps. 25, 26, 27, and 28 S., Rs. 22, 23, and 24 E.)

Samples were collected along the axis of the valley between Buena Vista and Tulare Lakes from wells at Smyrna, a well 6 miles southwest and one about the same distance northwest of Smyrna, which were relatively deep and at one time flowing. These wells, together with the wells at Semitropic, location 5, produced water with conductances between 19.7 and 49.8 and with 0.32 p.p.m. or less of boron; in each the percentage of sodium was relatively high.

The waters from a 170-foot well 7 miles west of Semitropic, location 4, and from a 112-foot well in the southeast corner of the quadrangle, location 6, had conductances of 133 and 155 respectively, boron concentrations of 0.40 and 0.34 p.p.m., and sodium percentages of 83 and 51.

QUADRANGLE 29

(Tps. 25, 26, 27, and 28 S., Rs. 25, 26, and 27 E.)

The four samples collected at locations 1, 2, 3, and 4 respectively at Delano, Wasco, Shafter (U.S. Cotton Field Station), and Famosa from wells of depths of 1,100, 600, 165, and 140 feet are typical of the good irrigation waters along the east side of the valley; the conductances were all less than 50, and the boron concentrations were 0.14 p.p.m. or less. A sample of Kern River water taken from Beardsley Canal is shown under location 5.

The other samples taken in the quadrangle are from wells in T. 28 S., Rs. 26 and 27 E. Some of the ground waters in this area are of inferior quality, and the group of samples as a whole affords an outstanding example of the variability that may be encountered in the quality of ground waters in a relatively small area. The conductances ranged from 32.3 to 444, the boron concentrations from 0.02 to 2.02 p.p.m., and the alkali base percentages varied from 4 to 86. The poorest of the waters, location 17, was from a well (now abandoned) drilled to 138 feet. The best of these waters, miscellaneous sample 6346, is from a new 765-foot well the casing of which was not perforated above 500 feet. This is the deepest well of the group, and its water now replaces for irrigation that from the location 17 well. Evidence afforded by the analyses of the samples first collected in the area pointed to the possibility of obtaining better water from deeper strata and also indicated the desirability of leaving casings unperforated at the higher strata.

The response of vineyards on rather light soil to the water represented by sample 6346 when it was substituted for water from the well at location 17 and a similar water was noteworthy in the rapidity with which improvement took place. After installing the pump on the new well, one half of a vineyard was given an irrigation in August 1931, and at the same time the other half was irrigated from the old wells. A month later a marked and unmistakable difference in growth was in evidence.

A well-cared-for vineyard irrigated from the well at location 16 is located across a roadway from a vineyard irrigated until September 1931 from the location 17 well. Both were in poor condition in 1931, but the latter was poorer. One year's irrigation with the no. 6346 water doubled the new growth on the later vineyard, whereas no evidence of improvement was shown in the location 16 vineyard. The location 16 water is much better than the location 17 water, but poorer than the new well water, both in total salinity and in the concentration of boron.

Sultanina grapes irrigated with water from the well at location 17 were observed in 1931 to have ripened properly, but the fruit was small and too round. Some of these vines were heavily fruited and others practically barren. Duplicate leaf samples collected September 16, 1930, from heavily fruited vines contained 1,048 and 1,093 p.p.m. of boron, and duplicate samples from immediately adjacent lightly fruited vines contained 1,231 and 1,230 p.p.m. The lightly fruited vines exhibited typical boron leaf injury. An inch or more of the leaf margins of the heavily fruited vines were dead, but the condition was not one that could be attributed directly to boron, since the same effect has been observed in heavily fruited vineyards irrigated with nonboron waters.

Ten ounces of anhydrous borax was applied by F. W. Herbert to a basin-irrigated Salwey peach tree on a light soil in a border row adjacent to cotton at the United States Cotton Field Station at Shafter, location 3, in May 1930. A leaf sample collected from the tree on October 30 of the same year contained 87 p.p.m. of boron, whereas the leaves of an untreated Muir peach contained 46 p.p.m. A year later pronounced boron symptoms were shown by the treated tree, and these were more marked on the side next to a roadway than on the side next to the irrigated cotton, into the soil of which roots of the tree undoubtedly extended. Leaves from the roadway side of the tree contained 165 p.p.m. of boron, and many leaves had been shed. Leaves from the cotton side contained 101 p.p.m. of boron. The leaves of the untreated Muir peach at the same time contained 47 p.p.m. of boron. The boron applied was equivalent to that which would have been applied by 48 acre-inches of water containing 1.9 p.p.m. of boron.

QUADRANGLE 30

(Tps. 29, 30, 31, and 32 S., Rs. 22, 23, and 24 E.)

Sample 2743 under location 2 in quadrangle 30 represents Kern River water as diverted through Buena Vista Lake Reservoir by canal. Other analyses of Kern River water are shown under location 1 of quadrangle 32.

Wells at locations 1 and 3, near and in Buttonwillow, were drilled to 230 and 220 feet, and the static levels were 10 and 14 feet. The two waters were essentially alike, having conductances of 91.6 and 91.4, boron concentrations of 0.47 and 0.38, and sodium percentages of 45 and 55. The chloride concentrations of each of these waters was much less than either bicarbonate or sulphate.

The water from the 730-foot Southern California Gas Co. well in T. 32 S., R. 24 E, with a conductance of 483 and a boron content of 4.14 p.p.m., is comparable in quality and in the proportions of ions to the poor waters found in quadrangle 27 to the northwest.

QUADRANGLE 31

(Tps. 29, 30, 31, and 32 S., Rs. 25, 26, and 27 E.)

The samples from locations 1 and 2 in quadrangle 31 represent waters which geographically and in quality are associated with those of T. 28 S., Rs. 26 and 27 E., of quadrangle 29.

The wells at location 3 near the Kern River north of Buena Vista Lake supply Taft with domestic water. Though this water had a conductance a little higher than any of the Kern River samples, its source is evident.

In a study of oil-field waters Rogers (*30*) has reported analyses of some samples in this quadrangle and many in quadrangle 30 to the west. He provides an extensive discussion of the ground-water situation in the latter area, but determinations of the boron concentrations were not made. According to Rogers' report the composition of a composite sample from shallow wells of the Western Water Co. in sec. 5, T. 31 S., R. 25 E., was as follows:

	Milligram equivalent per liter
CO_3+HCO_3	1. 69
Cl	9. 43
SO_4	3. 45
Ca	1. 56
Mg	.49
Alkali bases	11. 02

The Balbach well, location 4, lies below San Emigdio Creek, of which samples are reported under quadrangle 34. San Emigdio Creek is the probable source of this water, and the sulphate concentration, 15.33 m.e. is comparable with San Emigdio water as sampled April 27, 1930, but the concentrations of several other constituents are quite different; magnesium, for example, being present in the well to the extent of 33.4 m.e. and in the stream as diverted to the extent of 7.92 m.e.

Samples were obtained from four wells in section 7, 3 to 4 miles north of the location 4 well. One of these wells, sample 6811, was 237 feet deep, and the water, with a conductance of 193, had a composition not unlike San Emigdio Creek and that from the Balbach well. The other three wells, samples 6810, 6812, and 6820, were respectively 800, 600, and 800 feet in depth, two being reported as flowing. These wells, with conductances of 56.4, 68.7, and 54.0, were distinct in composition from the shallow well. The shallow well had a sodium percentage of 26, whereas the sodium percentages in the deep wells were 64, 50, and 69.

QUADRANGLE 32

(Tps. 29, 30, 31, and 32 S., Rs. 28, 29, and 30 E.)

Boron occurs in relatively high concentrations in the waters from a number of wells in the Caliente Creek delta near the Rock Pile School. The wells, at locations 22, 23, 24, 25, 26, 38, 42, 43, 44, 46, and 47 had upward from 0.96 to 7.24 p.p.m. of boron, and all were located in sections 12 and 13, T. 31 S., R. 29 E., and secs. 17 and 18, T. 31 S., R. 30 E. The conductances of these waters ranged from 41.3 to 138. Other wells nearby, locations 4, 14, 16, 18, 20, 27, 29, 41, 45, 52, and 53, some of which were in the sections enumerated, produced water containing boron in concentrations between 0.31 and 0.61 p.p.m. Other wells among those bordering the center of contamination and

wells farther removed therefrom (locations 11, 12, 13, 15, 19, 21, 28, 30, 31, 32, 33, 34, 35, 36, 37, 48, 49, and 50) produced water with 0.40 p.p.m. of boron or less, and a number contained less than 0.10 p.p.m. The conductances of the latter series of samples varied from 30.9 to 104.

The preponderant number of the foregoing wells varied in depth from 400 to 600 feet, and the elevation of the water table at the time of the work was for the most part between 350 and 375 feet above sea level.

Immediately east and north of the center of boron contamination near the Rock Pile School there is a second body of ground water at an appreciably higher elevation. This perched water table is separated from that of the lower plain by some underground barrier, marked possibly by the rocky outcrop known as the Rock Pile. The water of this upper table, as sampled from a 387-foot well on the Newmarket Ranch (location 8), a shallow well known as Deemer Spring (location 9), and Tejon Spring (location 39), had an elevation between 600 and 710 feet above sea level. The boron concentrations in samples from each of the three locations were in the order of 7 p.p.m. The location 8 water had a somewhat higher conductance and more sulphate than the water at 9, but otherwise the proportion of ions was such as to suggest that these three samples represented substantially the same water. In one respect other than boron this perched water is clearly different from that of the lower plane, namely, sodium is the predominant base, the percentages being 93, 92, and 96, respectively. The percentages of sodium in the samples of the delta water table varied from 22 to 87 percent, the average being 50 percent.

Farmers recognized in the early years of the agricultural development of this section, in which many of the soils are highly productive, that deciduous fruits could not be successfully grown with the waters from certain wells. It was also recognized that while some of the annual crops were injured, they withstood these waters better than grapes and deciduous trees. In one instance peach trees were observed to have shown marked improvement following a few irrigations with water from a new well. Prior to the investigations here reported boron determinations had been made on none of these well waters.

With the establishment of the fact that boron occurred in appreciable concentrations in certain of the well waters that had caused difficulty and that the concentrations were relatively low in other wells that were being used successfully, there were numerous solicitations by owners to have their well waters analyzed. The Kern River Water Storage District by well measurements had shown increasing elevations in the water levels from beyond the portion of the lower plane in which boron contamination was found toward the mouth of Caliente Creek. This fact indicated that at least during recent years and possibly over a long period Caliente Creek has made the principal contribution to ground waters of the area. Numerous well samples were collected and analyzed for the purpose of determining the extent of boron contamination, to enable the growers to adjust their water sources and choice of crops to the existing conditions. Some additional samples were collected and analyzed to throw light if possible on the source of the boron in the underground waters or the

source of the waters found to be high in this element. The evidence that it was possible to obtain for the latter purpose proved insufficient for general conclusions, but some of it is nevertheless worthy of brief discussion.

In one of the eastern lower-plane wells, location 42, the boron concentration was as high as in the perched water table, and in this well sodium constituted 87 percent of the bases. No other lower-plane water contained more than 77 percent of sodium, and most of them, though variable, were much lower. This well is the closest of any, the well at location 38 excepted, to a perched-water sample, and the concentrations of bicarbonate, chloride, and sulphate are essentially the same as in the location 39 sample from Tejon Spring of the perched table group. By these observations it seems to be indicated that water from the upper plane has to a limited extent found its way into a portion of the lower plane, possibly overflowing or passing through a fissure in the barrier.

A sample was bailed from an abandoned well at location 38, which is about 1½ miles northwest of Tejon Spring. The water elevation in this well corresponded with that of the lower plane, but sound in the well indicated that water was entering the casing in appreciable volume from a higher elevation. The sample obtained is believed to have represented the water entering the casing from above, but it was too small for other than conductance and boron determinations. The boron content, 6.90 p.p.m., corresponded with the concentrations found in the upper plane waters, but the conductance was far higher than that found elsewhere in either body. The observations afforded by this well are believed to indicate that at this point the perched water table overlies that of the lower plane, but that here the perched water is locally more saline.

An abandoned well in Caliente Wash, location 7, had a water elevation of 636 feet (134 feet below the surface of the wash), corresponding roughly with that of the perched table, but the boron concentration was less than 1 p.p.m. The stream-bed elevation and the elevation of the water in this well suggest a source of water, at least during freshets, for the perched table, but the low concentration of boron in the Caliente Wash well shows that if the water of the perched table is derived from Caliente Creek the boron is otherwise derived. The fact that the boron concentrations in the several samples from the three upper table locations and from the associated waters at locations 42 and 38 were all so nearly the same (6.66, 6.58, 7.51, 6.90, 7.24, and 7.12 p.p.m.) may indicate that somewhere this water has been in contact with boron minerals whose solubility was sufficient to produce an equilibrium concentration in the water of about 7 p.p.m.

The water-table elevations of the two wells north of Caliente Creek, locations 5 and 6, are comparable with the perched table south of the creek. These waters contained 0.21 and 0.28 p.p.m. of boron.

In the lower plane the well at location 24, now abandoned, was sampled four successive times in 1929 before it was capped. The boron concentration was essentially the same in each of the samples (4.51, 4.43, 4.63, 4.63), but the conductances varied as follows: 78.5, 55.0, 53.5, 83.4. There was a marked downward and a subsequen upward shift in the concentration of all ions except bicarbonate and sodium during the period. The sodium percentages, on the contrary, first increased and then dropped (50, 67, 70, and 46). These changes

in the concentrations of all ions except boron would suggest either a local release of boron by deep gaseous emanations in the vicinity of the well or deposits of boron minerals sufficiently soluble to produce boron concentrations of about 4.5 p.p.m. in the ground water. The characteristics of this water and the shifts in ionic concentrations with boron remaining practically constant would seem to eliminate the perched water table as a source of this local contamination.

Successive samples from wells at locations 22, 25, and 26 showed variations in boron concentrations which were not accompanied by variations of corresponding magnitude in conductances or ionic concentrations.

In Bakersfield a number of wells are pumped to supply municipal water, and the three samples obtained there show only moderate variations in the characteristics of the water on three dates. The total salinity of the samples was low, and the alkaline earth bases tended to exceed the alkali bases. The boron concentration in each of the samples was below 0.25 p.p.m. Mild boron symptoms are in evidence late in the season in the leaves of boron-sensitive plants along the streets and in parkings in Bakersfield.

Miscellaneous sample 928 is from Caliente Creek above Caliente Station, and sample 926 is from Tehachapi Creek above Keene. Caliente Creek, with a discharge of but 0.3 cubic feet per second on the date sampled, carried 0.87 p.p.m. of boron, and the location 7 well in the bed of Caliente Wash below carried 0.82 p.p.m. The conductance of the creek water as sampled in April was nearly three times as great as that of the well.

Sample 3915 from a shallow well east of Monolith represents foothill drainage on the Mojave Basin side of the Tehachapi Mountains.

The scattered samples from locations 3, 10, and 51 are all low in salinity and boron.

Leaf samples of various plants have been collected at one time and another in this quadrangle, and insofar as the boron-absorption characteristics of the different plants are known, the boron concentrations found have been indicative of the quality of water used for irrigation. Sycamore leaves from trees 18 miles south of Bakersfield along the highway to the Grapevine grade, watered from a well at location 2 of quadrangle 35 with 0.92 p.p.m. of boron, contained 1,843 p.p.m. of boron. Leaves of cottonwood from trees watered from the well at location 22, with 1.51 and 1.81 p.p.m. of boron by two analyses, contained 1,428 p.p.m. of boron. Under the well at location 24, with 4.63 p.p.m. of boron, grape leaves contained 1,155 p.p.m. of boron, persimmon leaves 847 p.p.m., and dooryard alfalfa (entire plants) 199 p.p.m. Cotton leaves under the well at location 46, with 3.52 p.p.m. of boron, contained 1,229 p.p.m. of boron. Fig leaves under the well at location 8, with 6.66 p.p.m. of boron, contained 1,853 p.p.m. The foregoing samples were all collected on September 23, 1929. Under the latter well other leaf samples were collected in June 1929, and the following was found: Tomatoes, 840 p.p.m.; Swiss chard, 85 p.p.m.; grapes of wild type, 1,120 p.p.m.; grapes, 722 p.p.m.; figs, 1,294 p.p.m.; olives, 87 p.p.m.; cannas, 1,483 p.p.m. On the same date grape leaves under the well at location 46, unirrigated that spring, had 930 p.p.m. of boron. Leaves of fig and walnut under the well at location 29 with 0.50 p.p.m. of boron contained respectively 500 and 656 p.p.m. of boron in October 1932.

Orange leaves from then unirrigated trees under the well at location 16, with 0.60 p.p.m. of boron, had 558 p.p.m. of boron. Leaves of eucalyptus trees near the well at location 43, with 4.64 p.p.m. of boron, contained 1,000 p.p.m.

QUADRANGLE 33

(Tps. 8, 9, 10, and 11 N., Rs. 24, 25, and 26 E. Quadrangle map not shown.)

Water piped to Maricopa from Ozena, which is near the head of Cuyama River, miscellaneous sample 2637, had a conductance of 49.6 and 0.23 p.p.m. of boron.

Numerous springs discharge near location 2 into Cuyama River, and these springs, together with water obtained from the stream bed, are diverted into a reservoir for irrigation on the Cuyama Ranch. Some of these springs are warm and produce sulphide gas. The concentration of boron in the reservoir sample was 0.23 p.p.m., which is the same as found in the Ozena water; but the reservoir water was very different in other respects and had a conductance of 184.

Sample 2738, at location 1, represents water brought to the surface with oil by Northern Oil Co. wells at Maricopa, which are drilled to a depth of about 1,000 feet. Like oil-well waters generally the chloride in this sample was high, and likewise the sodium. Subsequent analyses of oil-well waters elsewhere have shown the boron concentrations as well as chloride and sodium to be correspondingly high.

QUADRANGLE 34

(Tps. 8, 9, 10, and 11 N., Rs. 21, 22, and 23 W.)

San Emigdio Creek water is diverted at location 1 for irrigation on the San Emigdio Ranch. This water when used on oranges had not been satisfactory. Both the sulphate and boron concentrations were undesirably high. The series of samples here reported were collected to determine whether water of better quality could be obtained at some higher point on the creek. The analyses show that a considerable proportion of both the boron and sulphates are accumulated below location 5, which is 7 miles above the present diversion.

QUADRANGLE 35

(Tps. 8, 9, 10, and 11 N., Rs. 18, 19, and 20 W.)

El Paso Creek as sampled at location 1, where it is diverted for domestic, garden and orchard use at the El Tejon Ranch headquarters, had a conductivity of 47.5. This water, which is low in sodium, contained 0.40 p.p.m. of boron, which was just sufficient to produce mild but characteristic boron symptoms in lemons. Tejon Creek, miscellaneous sample 5006, from sec. 14, T. 11 N., R. 17 W., had a conductance of 85.2 and 0.15 p.p.m. of boron, and sodium constituted 15 percent of the bases.

Grapevine Creek and a well near the foot of the grade locations 2 and 3, which supply water for highway trees have slightly less than 1 p.p.m. of boron, and this concentration has been sufficient to produce outstanding injury to many of the roadside plantings. Sycamore leaves collected from highway trees 18 miles south of Bakersfield in September 1929 contained 1,843 p.p.m. of boron.

A sample of water from Castac Lake, sample 2619, location 8, taken at a time when the lake was low and the margins heavily

encrusted with salt, had a conductance of 7,919 and contained 299 p.p.m. of boron. The salts contributing to this high conductance were principally sodium chloride and sulphate. A spring in the mud flat immediately east of the lake margin produced water with a conductance of 138 and a boron concentration of 0.92 p.p.m. This spring water is different from Grapevine Creek water in its proportions of both magnesium and alkali bases. Wells west of the lake at locations 5, 6, and 7 contained 0.60, 0.35, and 0.51 p.p.m. of boron. Mild boron injury was noted on ornamental plantings around the hotel irrigated with the location 5 well and also on irrigated crops served by the other two wells. The injury was most pronounced on the field plantings grown on lower-lying portions of the fields closest to the lake. Leaves collected September 11, 1931, from a large oak tree at the end of the lane and outside of the cattle gate below Castac Lake contained 148 p.p.m. of boron.

Seymour Creek and Lockwood Creek, locations 10 and 11, which are in the vicinity of the Frazier borax mine, are tributary to Piru Creek. At the time of sampling in 1928 these creeks carried about 5 and 2 p.p.m. of boron, respectively, as determined by the semi-quantitative turmeric method. The same method was used for the determination of boron in the Cuddy Creek sample.

BACTERIAL REDUCTION OF SULPHATES

Attention has already been directed in the discussion of quadrangle 24 to the fact that the sulphate concentrations are remarkably low in the waters from deep wells in the bed of old Tulare Lake. These Tulare Lake bed irrigation wells are drilled to depths of 1,400 to 2,100 feet. One of them (location 13, quadrangle 24) had a conductance of 348, and yet in this water there was only a trace of sulphate. Of the 17 deep-well waters collected in the quadrangle, 6 contained 0.01 m.e. or less of sulphate, and the remaining 11 contained 0.40 or less m.e. per liter. Along the valley axis, north and south of the lake bed, and also to the east, there are other deep wells of moderate to high salinity in which the sulphate concentrations were likewise particularly low. Sulphates are practically absent in the warm and saline waters from the deep Stockton gas wells and from the gas well at Lodi. Waters examined west of the lake uniformly contained sulphate in excess of 1 m.e. per liter, and most of them contained much more than this amount. A group of three wells approximately 1,000 feet deep near the mouth of Kings River at the northern extremity of the lake margin of 1884 (locations 10, 11, and 12, quadrangle 20) contained about 6 m.e. of sulphate.

A demonstration that these low-sulphate, deep waters could not have been derived from the Sierra with as little sulphate as some now contain is scarcely necessary, as a certain amount of run-off from the coastal mountains at flood time reaches the valley axis and this water characteristically contains much sulphate. That waters with less sulphate entered the valley at an earlier period seems unlikely, since with the continued weathering of the softer mantle formations of the Sierra any changes in the quality of the run-off from the watersheds should be in the direction of lower salinity. The varied character of the waters underlying the area once occupied to fluctuating depths by Tulare Lake clearly indicates that a common source for all these waters cannot be assumed except as some of them

may have been altered by the formations with which they are or have been in contact. Inasmuch as the lower half of the well casings are commonly perforated, the water from any well is a mixture of that from many horizons. The composition of the lake waters during recent times does not provide information as to the source of these deep waters, but it does furnish evidence that recently and probably in the distant past waters accumulating along the valley axis were much more concentrated with respect to sulphates than the deep waters in question. Analyses made of the lake waters in 1880 and 1889 by the agricultural experiment station of the University of California and recomputed in parts per million from hypothetical combinations by Dole (*27*) show the compositions given in table 44, when expressed in milligram equivalents per liter.

TABLE 44.—*Chemical composition of the water of Tulare Lake* [1]

Constituent	Milligram equivalents per liter		
	Sample 1 [2]	Sample 2 [3]	Sample 3 [4]
Carbonate	0	0	0
Bicarbonate	12.04	12.37	31.88
Chloride	6.65	5.91	28.00
Sulphate	4.79	4.23	21.25
Calcium	1.00	.85	.70
Magnesium	1.96	1.72	1.07
Alkali bases	20.55	20.00	79.59
	Parts per million		
Total solids	1,400	1,401	5,188
Organic and volatile	39	76	276

[1] Analyses here reported in milligram equivalents were taken by Dole (*27, pp. 95, 281*) from the California University Agricultural Experiment Station report for 1890, appendix, and recomputed by him from hypothetical combinations to parts per million.

[2] Collected in January 1880.

[3] Collected in the spring of 1880. Lake elevation of samples 1 and 2 probably about 200 feet above sea level.

[4] Collected in February 1889. For the period 1883–97 the lake level was reported as fluctuating and generally low.

The evidence at hand strongly indicates that many of the deep waters underlying this portion of the valley have lost sulphates. In the presence of organic matter such loss is possible through the action of anaerobic bacteria, but insofar as the writer knows, sulphate reduction in fresh water of deep wells has not been demonstrated.

Sulphate reduction in natural waters by anaerobic micro-organisms has been demonstrated in the instance of the bottom waters of the Black Sea, as the classic example, and in river muds, brackish canal muds, sewage, soils, lake sands, springs, and dune sands. The presence of organic matter is essential to this reaction, and as a part of the reaction carbonate and sulphide are formed. Three species of sulphate-reducing bacteria have been described (*14*), and in one instance the reaction is attributed also to algae. More recently Rogers (*30*) attributed the low sulphate content of saline oil-associated waters of the Midway-Sunset oil field of the San Joaquin Valley to reactions with petroleum without the aid of living organisms. It was Rogers' belief that living bacteria could not exist in such situations. Bastin and his collaborators (*3*) took issue with Rogers' view and

undertook to show that the sulphate-petroleum reaction could take place only at very high temperatures. To determine if bacteria were not responsible for Rogers' phenomenon, these investigators first examined waters of Illinois oil sands and subsequently waters from the Sunset-Midway and Coalinga oil fields of California. Evidence of sulphate-reducing bacteria was found in all but 2 of the 30 Illinois oil-field waters examined, and the organism was isolated in pure cultures. Sulphate-reducing bacteria were found at depths of 760 and 3,090 feet in many but not all of the California low-sulphate oil-field waters. Bastin and Greer (*4*) later examined 8 fresh-water well samples and 1 river sample in the neighborhood of the Illinois oil fields. Negative results were obtained from the well waters, but sulphate-reducing bacteria were indicated as sparingly present in the river sample, which had some drainage from oil fields.

The following equations (*4*) are of the type of those that have been postulated to explain the results of these reactions:

1–a. $CaSO_4+CH_4\rightarrow CaS+CO_2+2H_2O$
1–b. $CaS+CO_2+H_2O\rightarrow CaCO_3+H_2S$
2–a. $Na_2SO_4+CH_4\rightarrow Na_2S+CO_2+2H_2O$
2–b. $Na_2S+CO_2+H_2O\rightarrow Na_2CO_3+H_2S$
3. $CaSO_4+2C\rightarrow CaS+2CO_2$
4. $MgSO_4+2C\rightarrow MgS+2CO_2$
5. $Na_2SO_4+2C\rightarrow Na_2S+2CO_2$

Should the presence of living sulphate-reducing bacteria in the deep-well waters in and about Tulare Lake and in the Stockton and Lodi gas wells be demonstrated by the appropriate bacteriological procedures, this would provide satisfactory evidence of the cause of the low sulphate concentrations here reported; but negative results from such tests would scarcely seem to disprove bacteria as the cause. There is reason to believe that these deep waters, lying as they do far below sea level, are practically stagnant and have been impounded for many years. The changes that brought about their present chemical make-up may have occurred at a much earlier time, and it is possible that the bacteria if once active might no longer be present. The writer cannot recall that combustible gases were present in any of the sulphate waters from wells west of the lake, but such gases (possibly methane) are of common occurrence in the lake waters. In one instance (location 15, quadrangle 24) a well emitted sufficient gas to support a flame several feet in height above a discharge pipe, and on still days it is sometimes dangerous to light matches near certain of these wells. The hydrocarbon requisite for the reaction is therefore present. The shallow well at location 18 emits much gas, but the water contained 2.18 m.e. of sulphate, which is less than that shown in the lake-water analyses. In this well active reduction may be in process, and living bacteria should be found here if anywhere.

As indicated by the literature and the postulated equations, free hydrogen sulphide is a common product of the reaction; but it does not follow that it should always be found in waters where the reaction has taken place. Should it not escape from the water, its precipitation as the sulphide of heavy metals is possible. The writer cannot recall that any of these wells produced water with a notable sulphide odor. Small amounts of the gas might, however, have escaped attention both in the field and in the laboratory, particularly in the wells that were producing other gas so freely. That sulphates could have been otherwise removed from the waters, as by precipitation with naturally

occurring barium, seems improbable; barium was not present in significant amounts, as no sample showed cloudiness when the bicarbonates were titrated with H_2SO_4.

Dole (*27*) has reported analyses and field "assays" of the ground waters of the San Joaquin Valley, and on the basis of his data and their interpretation he was led to conclude that the quality of these waters, specifically their sulphate content, provided an index to the source of the alluvium from which they were drawn. It was his contention that ground waters low in sulphate were from alluvium derived from the Sierra, whereas when considerable sulphate occurred in other than isolated instances that fact was believed to indicate that the alluvium had been derived from the coastal mountains. In its broader scope this interpretation is one of great interest and convenience in accounting for the varied character of the ground waters along the two sides of the valley, but its applicability to the axial waters may be open to question. In the writer's opinion the view becomes necessary that some of the valley waters have been altered by the action of organisms to the extent that their origin and the origin of the alluvium from which they are drawn is highly uncertain.

SUMMARY

Boron, the element that characterizes in part some 50 named minerals and such familiar compounds as boric acid and borax, is of agricultural importance by reason of its being essential to the growth of many if not all plants and also because it is highly toxic to many plants when present in the soil solution in concentrations of more than a few parts per million.

Boron has been found to be present in each of some 4,000 surface and underground waters so far examined in the western portion of the United States. In some of these waters its concentration has been sufficiently high to inhibit the growth of irrigated plants and in others so low that its presence was demonstrated only by special methods. This bulletin deals with the natural occurrence and the effects of boron particularly in reference to the agriculture of the San Joaquin Valley of California.

The spread between beneficial and toxic boron concentrations for some plants is narrow; in fact, concentrations that stimulate vegetative growth during the early development of the plant may be sufficient to produce mild evidence of injury as the older leaves mature. Boron concentrations found beneficial to some plants have prevented the growth of others. The differences in boron requirements and the differences in boron tolerance of even closely related plants cause the two phases of its effects on plant life to be closely allied. In some localities only crop plants relatively tolerant to boron have been found to grow successfully, though their selection had been by trial and error without knowledge of the cause of failures.

Boron applied in irrigation water tends to accumulate in the soil, and ill effects may appear only after a number of seasons and after investments have been made in permanent plantings or in the installation of expensive pumping equipment and irrigation systems.

Boron deficiency symptoms may be of varied character, but usually the younger leaves and growing points of plants are affected first. The apices may die back, or the terminal buds, if not killed, may remain dormant. The leaves of boron-deficient plants may be re-

duced in size, become irregularly chlorotic, dead areas may appear, and they may abscise prematurely. In some plants an arrested development of the veins takes place, resulting in a buckling of the mesophyll and irregularities in shape. The apical portions of the roots are often enlarged and stubby and fail to elongate normally. The symptoms of boron deficiency have been found to appear only when the boron available was considerably below the concentration required for the best growth of the plant.

Cotton, figs, grapes, alfalfa, beets, asparagus, and a number of other crops have shown increased growth when supplied with boron in concentrations above those that might be designated as traces.

Evidence of boron injury is manifested in the foliage of many plants by the yellowing and subsequent death of the marginal tissue. These effects normally appear first at the tips of the leaves and as more of the margin is affected progress toward the midvein or leaf base. Chlorophyll is retained longer in tissues near leaf veins. Leaves become cupped when marginal injury occurs in advance of full development. Affected leaves are abscised prematurely. The injury produced by boron may often be clearly differentiated from that produced by other causes.

The stone fruits, which rarely have leaf symptoms indicative of boron injury, are otherwise affected. The bark immediately below the nodes of prunes and apricots becomes thickened, and with the overgrowth of underlying wood the structures at the bases of leaves and twigs become enlarged. The bark above the leaf and twig insertions of peaches and prunes often breaks down and splits open. Gumming frequently accompanies these abnormalities. Death of the terminal growth late in the summer or over winter is a common effect. Some stone fruits may make little growth or die without the development of marked symptoms. In pear and apple, symptoms adequate for field diagnosis are not known, yet these plants are sensitive to boron.

The growth of lemons, grapefruit, and avocados is sharply reduced in sand cultures supplied with nutrient solutions containing 3 p.p.m. of boron; such plants as the stone fruits and pears in cultures supplied with 6 to 9 p.p.m.; cereals, olives, and cotton in cultures with 15 p.p.m.; carrots, onions, and beets with 25 or more p.p.m.; whereas date palms, asparagus, and athel withstand up to 100 p.p.m. Fifty-four plants are listed in the order of their relative tolerances.

All varieties of plants examined have been found to contain boron in their tissue, though marked differences exist in the concentrations in the different varieties when grown under similar conditions. Marked differences likewise have been found in the concentrations in different parts of plants and in different portions of tissues. The fact that boron in some quantity has always been found in plants irrespective of where they were collected provides evidence of the widespread distribution of the element.

In sand cultures supplied with nutrient solutions containing 5 p.p.m. of boron, the leaves of various plants contained boron in parts per million on a dry-weight basis as follows: Lemon, 1,232; avocado, 569; apricot, 99; Kadota fig, 722; grape, 1,046; apple, 143; elm, 943; olive, 215; sweet pea, 520; cotton, 306; carrot, 124; sugar beet, 177; palm (pinnae), 279. These plants are listed in the order of their relative tolerance. The stems and roots of plants contain less boron

than the leaves. Those of lemon, elm, rose, and sugar beet contained respectively 54, 22, 29, and 28 p.p.m. The boron concentrations in different parts of other plants are reported.

The midveins, green portions, yellow portions, and dead portions of injured lemon leaves contained respectively 47, 438, 1,060, and 1,722 p.p.m. of boron.

Boron accumulates in the bark of certain of the stone-fruit trees, particularly at the nodes; and these plants, which develop wood and bark abnormalities, do not accumulate as high concentrations of boron in their leaves as do many other plants. Injured prunes contained in their leaves, bark, and wood respectively 176, 412, and 171 p.p.m. of boron, whereas uninjured prunes contained in the same parts 33, 36, and 11 p.p.m., and injured lemon twigs contained 410, 42, and 9 p.p.m.

Notwithstanding evidence of the occasional occurrence of appreciable concentrations of boron in unirrigated soils in the San Joaquin Valley, the general inference to be drawn from the appearance of crops is that the boron carried by irrigation water is for the most part responsible for such depressions in yield and such crop injury as have occurred.

Much of the boron found in soils, whether irrigated or not, is not very soluble. Soils are capable, in varying degrees, of removing from solution some of the boron applied by irrigation waters. A few or many irrigations may be applied before the soil-solution concentrations equal or exceed the concentrations of boron in the water used. Injury to plants results sooner on light soils than on heavy soils, and sooner on some heavy soils than on others, when boron-contaminated irrigation waters are used. The productivity of light soils may be restored more rapidly than that of heavy soils when leached with good water, but removal of boron from light soils is often slow.

The nature and quantity of soluble or slightly soluble boron compounds in the soil determine soil-solution concentrations, and it is the latter concentrations that affect plant growth.

Under the usual conditions in irrigated regions, plants withdraw a greater proportion of the water than of the salt from the soil solution and the soil solution, as a result of transpiration, is left more concentrated. Few irrigation waters of the San Joaquin Valley were found to contain concentrations of boron or other salt constituents sufficiently high to be directly injurious to plants. Injury has resulted from the continued use of many of these waters because transpiration and evaporation increase the concentration of these elements in the soil solution. Mixed deciduous fruits were grown in sand cultures with nutrient solutions containing 1 and 6 p.p.m. of boron. The solutions taken up by these trees were respectively 14 and 16 percent as concentrated in boron and 5 and 7 percent as concentrated in sulphate as the culture solution supplied to the roots. In a culture supplied with 9 p.p.m. of boron in which the grape was the predominating plant the solution taken up was 32 percent as concentrated in boron and 21 percent as concentrated in sulphate as was that supplied.

Practical methods of removing the boron from irrigation water have not been found, nor have practical methods been found for counteracting the toxic effects of boron in soils. Citrus plants withstand boron a little better when nitrates are applied in abundance.

Where satisfactory waters cannot be had, the diversity in crop tolerances provides recourse in the substitution of crops of suitable tolerances to boron injury. A table of crop tolerances is presented.

The San Joaquin Valley, which is a great structural trough, has a rainfall of about 5 inches toward the southern or upper end and about 15 inches at the northern end. The principal supplies of surface water and the underground water of the east side of the valley are derived from streams arising in the granitic, metamorphic, sedimentary, and igneous formations of pre-Cretaceous age of the high Sierra Nevada. The water of these streams carries little boron or other mineral matter. Smaller streams enter the valley from the Tehachapi and San Emigdio Mountains, which form the southern boundary of the valley, and from the coastal mountains that form the western boundary of the valley. All of the latter streams are short and except after heavy rains bring little water to the valley. These waters, draining mountains practically free from granitic and similar rocks but with soft serpentines, shales, and sandstones of Cretaceous and Tertiary age, are more highly mineralized than water from the Sierra and commonly contain appreciable concentrations of boron. In their chemical characteristics the ground waters in the different portions of the valley reflect their source or the source of the alluvial material from which they are drawn.

Boron concentrations as low as 0.5 p.p.m. in irrigation waters of the more arid portion of the valley have been found injurious to boron-sensitive crops, but under favorable conditions the more tolerant of the sensitive crops may be grown with only moderate reductions in yield with as much as 1 p.p.m. of boron in the irrigation water. When boron concentrations exceed 1.5 or 2 p.p.m. the best results have been found to follow when tolerant crops were cultivated.

The effects of boron in irrigation water are less severe in those parts of the valley with higher rainfall. Where water is supplied nearly equally by rain and irrigation, only about half the injury experienced in the more arid portions of the valley has been found. Soil characteristics, cultural practices, and length of use influence the rate at which boron accumulates in the soil solution and the accompanying effect upon crops.

Though no general relationship has been found to exist between the concentration of boron and the concentration of any other constituents of irrigation water, there is a marked tendency in the San Joaquin Valley toward higher boron concentrations in the more highly mineralized waters.

The ill effects of boron and of other salt constituents are in a measure interrelated and additive. In these investigations the concentrations of carbonate, bicarbonate, chloride, sulphate, calcium, magnesium, and alkali bases in the irrigation waters have been determined. A discussion of the significance of these other constituents of irrigation water is included.

Some San Joaquin Valley irrigation waters contain more sodium than calcium and magnesium. High percentages of sodium have an adverse effect upon the physical condition of soils by causing them to become hard and relatively impervious to water. Irrigation water that penetrates beyond the root zone carries with it a portion of the salts residual from transpiration and evaporation. Without adequate leaching the concentration of the soil solution may become sufficiently

high to depress plant growth even when relatively pure irrigation water is used. Emphasis is placed on the importance of the sodium percentage as a useful criterion of water quality, and in reporting the analyses of 450 San Joaquin Valley waters the percentage of sodium in each sample is given. The calculation and inclusion of these percentages represent a new departure, which is recommended for general adoption in reporting water analyses. Water with less than 50 percent sodium should not cause trouble in hardening the soil. Trouble is likely to result when the percentage exceeds 60.

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THE PEPPER WEEVIL[1]

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The Bureau of Entomology and Plant Quarantine in Cooperation with the California Agricultural Experiment Station

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ECONOMIC IMPORTANCE

The pepper weevil (*Anthonomus eugenii* Cano) (fig. 1) is a serious pest of peppers (*Capsicum* spp.) wherever they are grown in the Southwest, especially in southern California, Texas, and New Mexico. In California, where the industry is the largest, it has caused losses to growers amounting to 50 percent of the crop in some years; in Texas heavy losses have been experienced every few years since 1904; and in southern New Mexico there have been serious losses periodically for several years.

[1] *Anthonomus eugenii* Cano; order Coleoptera, family Curculionidae. Also called the chili weevil, and in Mexico the "barrenillo."

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[3] The authors' thanks are due to A. G. Böving, of the Division of Insect Identification of the Bureau of Entomology and Plant Quarantine, for drawing the larva and pupa and assisting with the larval description, and to Mrs. M. F. Benson, Division of Truck Crop and Garden Insects of the same Bureau, for drawing the larval mouth parts. Acknowledgments have been made in the text to those who have assisted in determining material.

Prior to 1923, when the pepper weevil was first reported in southern California, from 8,000 to 10,000 acres in this State alone were devoted to pepper growing, and the crop was valued in excess of $1,000,000 annually. In southern New Mexico about 3,000 acres of peppers are grown each year.

During 1924 and 1925 the average loss from weevil damage in California was light, ranging from none in many fields to 50 percent in 1 or 2 small fields. In 1926, following a mild winter, the loss to the industry was estimated at 50 percent, or about $500,000. In many fields the crop was a total loss by midseason, and in others it was common to harvest only one-fourth ton per acre where 5 tons were expected. In 1927, following a severe winter, the weevil appeared late and in small numbers, and the average loss was esti-

FIGURE 1.—Two views of the pepper weevil (*Anthonomus eugenii Cano*), ×10.

mated at less than 15 percent. In 1928, following a mild winter, infestations were again heavy, and the average loss was about 25 percent, with a range of damage, in the fields examined, from less than 1 to 75 percent. The losses would have been heavier had not control measures been practiced by a large number of growers. In the hope of reducing these losses, a laboratory was established in southern California, and a thorough study has been made of this insect and of the injury that it causes.

DISTRIBUTION

A survey in California in 1924 showed the weevil to be present in Los Angeles County near La Habra, Puente, Pomona, Norwalk, Long Beach, Alhambra, and San Fernando; in Orange County near Fullerton, Anaheim, Garden Grove, Santa Ana, and Costa Mesa; in Riverside County in the city of Riverside; and in San Bernardino County at Chino. At the end of the 1925 season no additional distribution points were noted. The season of 1926 was characterized by very heavy infestations, and the weevil spread to San Onofre, Bonsall, and Vista in San Diego County. In 1927 infestations were discovered at Fontana, San Bernardino County; at Saticoy, Ventura County; and at El Cajon, La Mesa, and Oceanside, and in the Mis-

sion Valley, of San Diego County. By the end of the season of 1928 weevil infestations were common in all the pepper-growing sections of the counties of Los Angeles, Ventura, San Bernardino, Riverside, Orange, and San Diego.

In Texas the pepper weevil has been reported from the counties of Kendall, Bexar, La Salle, Cameron, Kerr, Kleberg, Hidalgo, Harris, Atascosa, and El Paso. In New Mexico it has been reported from the counties of Eddy, Otero, Dona Ana, Luna, Hidalgo, Grant, Sierra, Chaves, Socorro, and Bernalillo.

In 1927 the weevil was reported from Douglas, Ariz., approximately 1½ miles north of the Mexican boundary, but there are no other reports of its occurrence in Arizona.

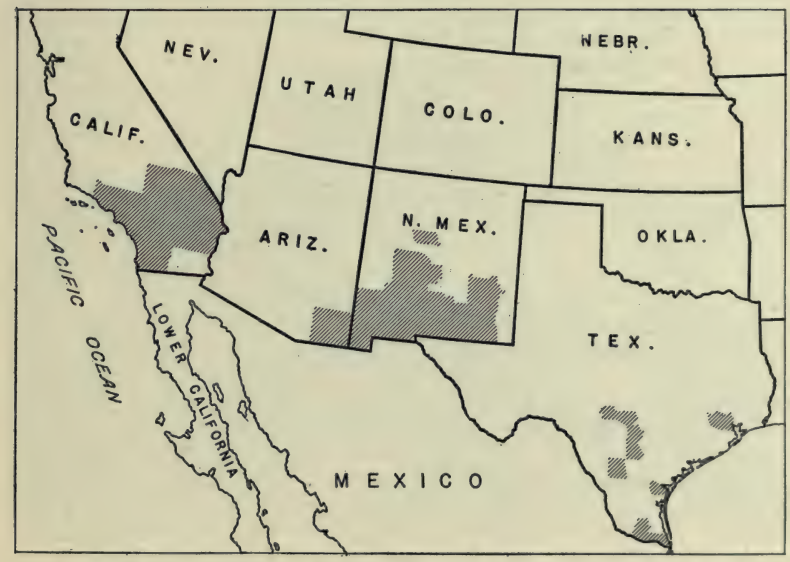

FIGURE 2.—Distribution of the pepper weevil in the Southwestern States.

Reports of the occurrence of the pepper weevil in Mexico indicate that it may be found in the States of Zacatecas, San Luis Potosi, Jalisco, Guanajuato, Durango, Sonora, Sinaloa, Morelos, Vera Cruz, Guerrero, and Oaxaca.

The pest made its appearance in Honolulu, Hawaii, early in 1933, and has been found widely spread on the island of Oahu.

A map of the distribution of the pepper weevil in the Southwest is shown in figure 2.

HISTORY

The first published record of the pepper weevil as a pest of peppers appeared in 1894, when Cano (*2*)[4] described it as *Anthonomus eugenii*, from Guanajuato, Mexico. In 1903 Champion (*3*) described it as *A. aeneotinctus*, giving its habitat as Guanajuato, Tupataro, Sayula, Jalapa, Orizaba, and Amula, Mexico.

[4] Italic numbers in parentheses refer to Literature Cited, p. 26.

The earliest record of the occurrence of the pepper weevil in the United States was made in 1904, when Walker (*13*) reported sweet peppers collected at Boerne, Tex., to be infested with a species of *Anthonomus* determined by Schwarz as *A. aeneotinctus* Champ. Walker briefly discussed the habits of this species and the seriousness of its damage to peppers, and gave a short general description of its different stages. According to pepper growers in that locality, the pepper weevil had been noticed there during the two preceding seasons and had caused "a loss of more than one-third of the crop each year." In 1907 Pratt (*12*) reported that many truck growers at San Antonio, Tex., had given up the growing of peppers on account of the destructiveness of the weevil the preceding year, and that in one field this pest had attacked fully 80 percent of the pods. Pratt expressed the opinion that the pepper weevil had been introduced into the United States from Mexico. It seems that peppers grown in Mexico and shipped to several localities in Texas were reshipped and sold as grown in this State. If these peppers had become infested in Mexico, the insect might easily have been introduced into the United States in this manner. According to Pratt, pepper weevils had been collected at Tlahualilo, Durango, Mexico.

In 1909 M. M. High reported the loss of an entire crop in the lower Rio Grande Valley in Texas from the ravages of this insect, but he failed to find the weevil again until 1913, when he observed a few specimens. In 1917 R. M. Halstead, San Luis Potosi, Mexico, sent several green peppers infested with weevils to the Bureau of Entomology of the United States Department of Agriculture, referring to them as a "serious menace to peppers." In 1921 J. M. Del Curto, of the Texas Department of Agriculture, reported that a weevil was destroying the pepper crop in the lower Rio Grande Valley, and that "in some instances the plague was so serious that the entire crop was lost." Specimens that he sent to the Federal Bureau of Entomology were determined as *Anthonomus eugenii*. Another note showing the presence of the pepper weevil in Mexico, and throwing light on its possible introduction from there into the United States, was furnished by the California Department of Agriculture. It states that "C. H. Vary at Los Angeles, in July 1922, took a number of specimens of *Anthonomus eugenii* Cano from a shipment of Mexican-grown peppers." In 1924 Charles H. Gable, San Antonio, Tex., reported the pepper weevil as a very serious pest and stated that the growing of peppers in that locality was usually abandoned after the middle of July because of the seriousness of the infestations.

The first authentic record of the pepper weevil's occurrence as a pest of peppers in California was made in 1923, when Campbell (*1*) reported heavy losses to growers of bell peppers at La Habra. About the same time the weevils were also found near San Juan Capistrano and in the San Fernando Valley. In 1924 infestations were found to be general over Orange and Los Angeles Counties. Pepper growers claim to have observed the injury for several years previously, describing the damage as "worminess" or "drop."

HOST PLANTS

The host plants of the pepper weevil are limited to genera of the Solanaceae, *Capsicum* (pepper) and *Solanum* (nightshade). The common varieties of the pepper, *C. annuum* L.,[5] the pimiento, tabasco, chili, and bell peppers, as well as *C. baccatum* L.,[6] are very susceptible to weevil attack, but varieties bearing the thinner walled fruit suffer heaviest losses. The pepper weevil is common on black nightshade (*S. nigrum* L.)[7] (fig. 3) in pepper-growing areas of southern California, breeding in the berries and surviving on the abundant foliage of the perennial form *douglasii* during the winter. Other wild nightshades upon which the pepper weevil may occa-

FIGURE 3.—Nightshade (*Solanum nigrum*), wild host of the pepper weevil.

sionally be found when growing near infested pepper fields are *S. xanti* A. Gray, *S. umbelliferum* Esch., and *S. villosum* Mill. Adult weevils have also been found on two species of ornamental nightshade (*S. glaucum* Dunal and *S. aviculare* Forst.) during the winter. On several occasions two varieties of eggplant (*S. melongena* var. *depressum* Bailey and var. *esculentum* Nees) have become infested with the pepper weevil when growing near heavily infested pepper fields. From the standpoint of economic losses, the pepper is the most important host plant. Black nightshade is also important because it is continually a source of infestation of pepper fields.

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[5] Jones and Rosa (9) refer to Irish (1898) as listing the varieties of pepper in the United States under two species, *Capsicum annuum* and *C. frutescens*, and to Bailey (1924) as listing them all under one species, *C. frutescens*.

[6] This species grows wild in southern Texas and is cultivated to some extent there and in California. Determined as *Capsicum baccatum* by Mrs. R. E. McDonald.

[7] N. L. Gardner, curator, and W. W. Robbins, professor of botany, University of California, recognize only one species (*Solanum nigrum*) of black nightshade in California. Jepson (8) lists *S. nigrum* as the annual form and *S. douglasii* Dunal as the perennial form.

Other plants[8] of common occurrence in and near pepper fields which have been tested as hosts include *Amaranthus graecizans* L., *A. retroflexus* L., *Ambrosia psilostachya* DC., *Bidens pilosa* L., *Brassica* sp., *Chenopodium album* L., *Datura stramonium* L., *Daucus carota* L., *Helianthus* sp., *Lycopersicum esculentum* Mill., *Malva borealis* Wallm., *Medicago hispida* Gaertn., *M. sativa* L., *Melilotus indica* (L.) All., *Physalis ixocarpa* Brot., *Salix* sp., *Salsola kali tenuifolia* G.F.W. Mey., *Sonchus oleraceus* L., *Urtica urens* L., and *Zea mays* Com. The adult weevils fed sparingly for a few days on several of these plants, but egg laying was not observed in a single case. Eggs that were transferred to tomatoes and the pods of *Datura* sp. and potato failed to develop. Eggs and young larvae transferred to pods of *Physalis ixocarpa* developed in a number of cases.

FIGURE 4.—Pimiento pepper plants, showing pepper-weevil damage.

Cano (*2*) says that the pepper weevil may feed on corn, but the writers have been unable to compel adults to feed on young corn plants.

CHARACTER OF INJURY

The most important damage is the destruction of blossom buds and immature pods. (Figs. 4 and 5.) The crop may be entirely lost if the infestation is both severe and early. The stems and calyces of infested pods first turn yellow, and, as the grubs continue to grow, the stems begin to wither at their junction with the plant. The pods then turn yellow or prematurely red and fall from the plant. Very often they are malformed. In many cases the first sign of infestation that the grower notices is a few fallen pods, but by this time serious damage may be already done and within the next 10 days a large part of his crop may fall.

[8] Plants determined by N. L. Gardner, of the University of California, and Frank Pierson, of Pasadena, Calif.

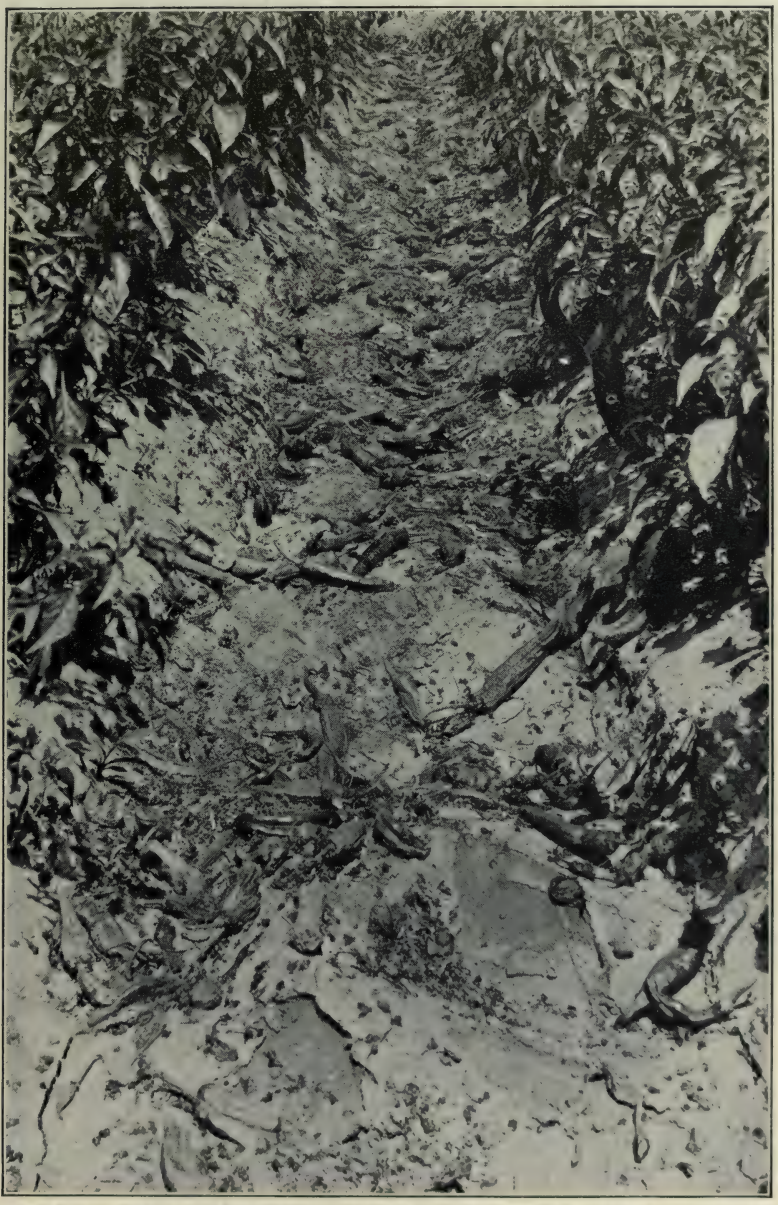

FIGURE 5.—A heavily infested field of California chili peppers, showing concentration of infested pods at end of row where irrigation water has carried them. Infestations become very heavy on plants surrounding such places.

Even if a few infested pods remain on the plant and reach maturity, they are often marred by weevil exit holes (fig. 6). The feeding of the grubs within the pods causes the seeds and cores to turn

FIGURE 6.—Infested chili-pepper pods, showing larvae, typical blackened condition of seed core, and exit holes.

black, and often an entire core becomes a mass of decayed tissue and frass. Pods that appear to be sound may show this condition when opened (fig. 7).

Feeding punctures in the pods do not materially damage peppers intended for drying, but they appear as dark specks at the bottom of depressed areas and lower the quality of fruit used green or for canning. In the latter case the punctures appear as black spots when the peppers are cooked.

Damage to blossom buds is similar to that done to pods, the larvae within the bud causing it to fall. Unless weevils are very numerous, however, this natural pruning is not serious, since the plant always sets many more buds than are needed to produce a normal crop and these are lost even when not infested. Feeding punctures in the buds cause them to drop.

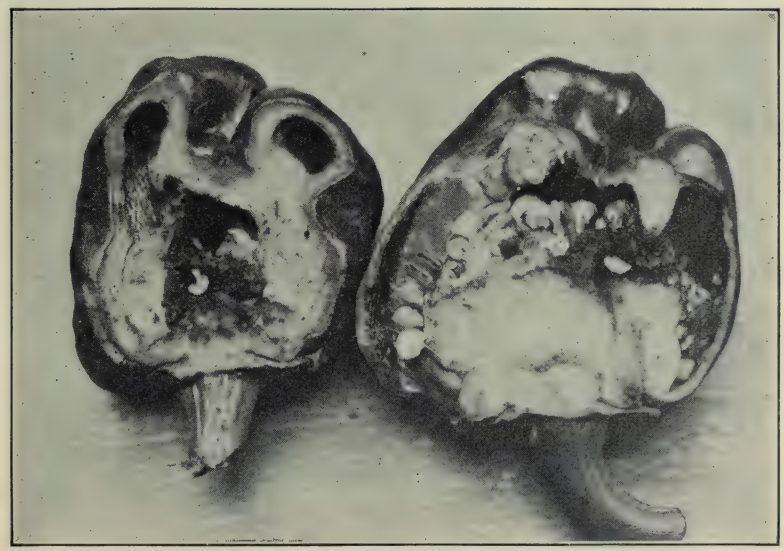

FIGURE 7.—Injury to bell-pepper pods by the pepper weevil.

Buds and immature pods are susceptible to weevil attack at any time, but weevils are unable to puncture mature pods because of the resistant character of the epidermis. In favorable localities the first fruit matures before the weevils become numerous, and sometimes good yields result in spite of heavy infestation later in the season. Late crops and those intended for winter production are often entirely destroyed.

DISSEMINATION

Dissemination is accomplished by flight during the active season and on warm days during the winter. The weevils have been observed in flight in every month of the year. The transportation of infested peppers, picking sacks, and young pepper plants has been known to introduce the pepper weevil into new localities. On three occasions adult weevils were known to have been carried about 15 miles on the windshield of an automobile.

SOURCES OF FIELD INFESTATION

The earliest infestations of the newly planted pepper fields in the spring generally originate from nightshade growing along ditch banks, fence rows, at the edge of wooded areas (fig. 8), or around buildings, or from pepper plants that have lived through the winter (fig. 9), and they usually begin in the part of the field nearest one of these situations. In the season of 1928, early infestations in 18 out of 20 locations were traced directly to nightshade or to old pepper

FIGURE 8.—Nightshade as a source of infestation at the edge of a eucalyptus grove.

fields, and in 1929, 14 out of 18 early infestations were traced directly to nightshade. Later infestations are due largely to dissemination of the insects from the first fields to become infested.

The degree of infestation is easily correlated with the relative number of weevils overwintering in each locality. Weevils have been observed breeding in nightshade berries throughout the growing season, and their flight into pepper fields had some effect on the progress of infestations.

Another source of field infestations is the seed bed. Weevils infesting seed beds, which are usually under cloth, have been known

to complete one generation by the time the plants were ready to be transplanted. When the plants are distributed the weevils may be scattered.

PROGRESS OF AN INFESTATION IN A PEPPER FIELD

FIGURE 9.—Infested pepper field in which eggs were found in buds on February 20, 1931. The average winter population in this field is one adult per plant.

In a pepper field the normal infestation, based on the number of punctured buds and pods (referred to as "forms"), is not more than 1 percent when the first buds have formed. The percentage may increase in proportion to the number of weevils entering the field. The infestation gradually spreads over the entire field and then increases in intensity until sometimes it is almost impossible to find an uninfested immature pod. An infestation may or may not be uniform in intensity throughout the field. Figure 10 illustrates the progress of an infestation by showing the characteristic curve representing pepper-weevil increase. The percentages were calculated from counts of infested and uninfested forms in representative ⅓-acre plots in two fields, 3 plots in field 1 and 2 plots in field 2. A total of 30 plants at 9 different points were examined in each plot. The number of forms counted at each examination ranged from 828 to 6,768.

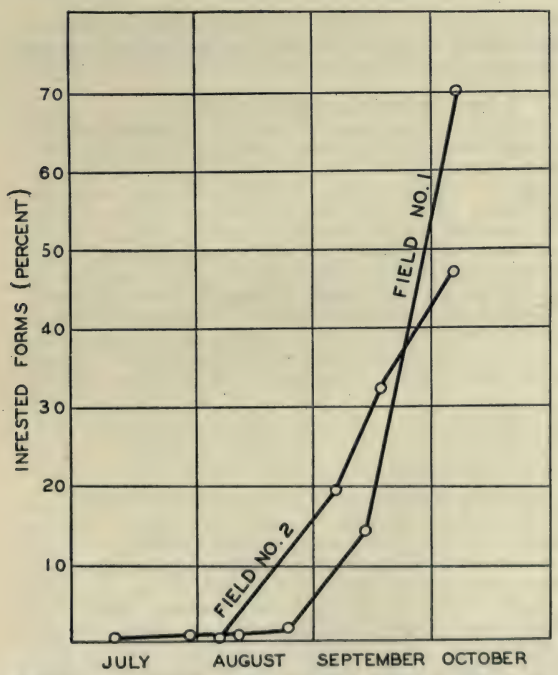

FIGURE 10.—Progress of pepper-weevil infestation in two fields.

DESCRIPTION

ADULT

Champion's description (*3, p. 169*) of this insect, which he called *Anthonomus aeneotinctus*, is as follows:

Subovate, shining, nigro- or rufo-piceous, with a brassy lustre, the antennae (the club excepted), the base of the femora, the tibiae, and tarsi rufo-testaceous or testaceous; somewhat thickly clothed with coarse whitish or pale ochreous pubescence, which is denser on the scutellum and is sometimes here and there clustered into small fascicles on the elytra. Rostrum (♂) curved, moderately stout, a little longer than the head and prothorax, rugulosely punctate and obsoletely carinate, (♀) more elongate, the antennae in the ♂ inserted at about one-third, and in the ♀ at about two-fifths, from the apex. Prothorax transverse, narrowed and constricted in front, closely punctate. Elytra about one-half wider than the prothorax, subparallel at the base; deeply punctate-striate. Femora each with a small tooth; anterior and intermediate tibiae strongly sinuate within: tarsal claws with a long tooth.

Var. The prothorax with three narrow vittae, and the elytra with alternate interstices in part, clothed with whitish, and the rest of their surface with ochreous, pubescence.

Length 2½–3⅒, breadth 1⅓–1⅞ millim. (♂ ♀).

Hab. Mexico, Guanajuato (*Sallé*), Tupataro, Sayula, Jalapa (*Höge*), Orizaba, Amula (*H. H. Smith*).

Very like *A. mexicanus*, and perhaps an extreme form of it, but a little larger and with the pubescence in fresh specimens nearly as dense as in *A. grandis*. The variety is represented by two females from Amula.

Champion later (*4*) acknowledged Cano's earlier description under the name *Anthonomus eugenii*.

The authors have considered it advisable to redescribe the insect, including characters that were omitted from earlier descriptions and noting certain variations.

Anthonomus eugenii Cano. Robust, subovate, convex, nigropiceous to nigrotestaceous, the integument strongly shining and often with a brassy luster; beak rufopiceous to nigropiceous, head nigropiceous, joints of antennae rufotestaceous, club piceous; legs varying from piceous, with bases of femora and apices of tibiae testaceous or rufotestaceous, to rufotestaceous with the tibiae somewhat darker and bases of femora nigrotestaceous; body clothed with gray or ochraceous, flat, scalelike hairs, densely on the elytral intervals, sterna, and flanks of the abdomen, very densely on the scutellum, and rather sparsely on the legs, prothorax, and head. Beak fairly stout, moderately curved, one-sixth longer than the head and prothorax, rugosely punctate, more strongly so basally, with a series of 5 faint carinae, 1 dorsocentral and 2 on each side, extending to or slightly beyond the insertion of the antennae. Head thick, convex, with sparse shallow punctures; eyes rounded, convex. Antennae fairly long, thin, the club oblong. Prothorax not strongly convex, strongly and densely punctate; one-third wider than long, slightly narrowed behind, base truncate; apex truncate, two-thirds as wide as base; sides subparallel to the anterior three-fifths, thence strongly converging, with a very slight constriction at the anterior fifth or sixth. Scutellum small, oblong-oval. Elytra strongly punctate-striate, the intervals appearing smooth, but minutely and sparsely punctulate beneath the scales, flat; together one-third wider at base than the base of the prothorax, one-third longer than wide; humeri prominent, rounded, sides subparallel to the middle, thence smoothly, evenly rounded, apices separately rounded; low, rounded protuberance on declivity of each elytron, just anterior to junction of third and eighth striae. Femora each with a small, acute tooth, those on the anterior femora longer and sharper. Anterior and middle tibiae sinuate within, posterior tibiae less so. Tarsi spongy beneath, rufotestaceous, tarsal claws black, each with a long tooth within. Length, exclusive of beak, 1.9 to 3.7 mm, averaging about 3 mm; width 1.1 to 2 mm, averaging 1.7 mm.

In most specimens that have emerged from pupae in capsules the elytra are completely clothed. In others there is a denuded area on each elytron. In young specimens this is small, extending from the posterior three-fifths to the posterior four-fifths and between the second and fourth striae. In older specimens it may be much enlarged, extending from the middle to the apical four-fifths and between the first or second and the seventh striae or even farther.

The adult pepper weevil is about 3 mm long and 1.5 to 1.8 mm wide. The size varies according to the food available for larval development. The thorax and wing covers are clothed with an ochraceous pubescence, but the derm may vary from light brown to black.

There are marked, though somewhat variable, differences between the secondary sex characters of the male and female. The characters which follow are, according to Dietz (*5*, *p. 178*), common to the Anthonomini and therefore applicable to the pepper weevil:

Beak of female more slender and slightly longer than that of male, but usually less coarsely punctured and more shining. Antennae inserted slightly farther from tip in male, and beak when observed from above usually appearing to taper slightly from each end toward the middle. Abdomen of male showing eight distinct dorsal segments, terminal segment (pygidium) not being entirely covered by propygidium as in the female. Hind tibial mucro much broader in male than in female. The characters of the beak, however, are usually sufficient to determine the sex, when both are present.

THE EGG

Average length 0.53 mm, diameter 0.39 mm; pearly white when first laid but later yellow; usually oblong-oval, but sometimes having irregular shape of cavity in which it lies; shell smooth, shiny, flexible, and rather tough.

THE LARVA
(Figs. 11 and 12)

Mature larva about 6 mm long, cylindrical, and curved (fig. 11). Body white, although appearing gray when digestive tract is filled; head yellowish brown with brown margins and dark-brown mandibles. Prothorax slightly narrower than mesothorax or metathorax, which are almost as wide as first abdominal segments. No unusual arrangement of body areas, but limiting grooves shallow or absent. Prothorax with continuous dorsal sclerite carrying 7 setae on each side. Mesothorax and metathorax each showing 2 dorsal bulges, a prescutellar area (*ps*) and a fused scutoscutellar area (*sc-scl*); prescutellar area carrying 1 minute seta, scutoscutellar area 3 setae on each side; alar area (*a*) present, carrying 1 seta. Pedal lobes (*p*) distinct but not protuberant, each carrying 4 setae. First to fourth abdominal segments with 3 dorsal bulges each, a prescutal (*psc*), a scutal (*sc*), and a scutellar area (*scl*); rest of abdominal segments without distinct dorsal areas. Epipleural lobe (*e*) circular and large but poorly defined on all abdominal segments, the lateroventral furrow being almost indistinguishable. Hypopleural area (*h*) and sternal areas present but indistinct. Setae minute and usually broken off, but occasionally distinguishable on one or a few segments; distributed on each side as follows: 1 on prescutal, 3 on scutellar area, none

FIGURE 11.—Larva of *Anthonomus eugenii*, ×12.

on scutal. Posterior end of ninth abdominal tergum prolonged into a thick, rather short, conical projection; tenth abdominal segment wart-shaped, with large anal opening. Spiracles (fig. 12, *F*) small, biforous; spiracular opening (*o*) cup-shaped; air tubes (*t*) directed posteriorly, each tube with 5 or 6 annuli (*ann 1, ann 2*), and closing apparatus with 1 long and 1 short arm; 1 pair of spiracles on mesothorax, 8 on abdomen, all lateral and of equal size.

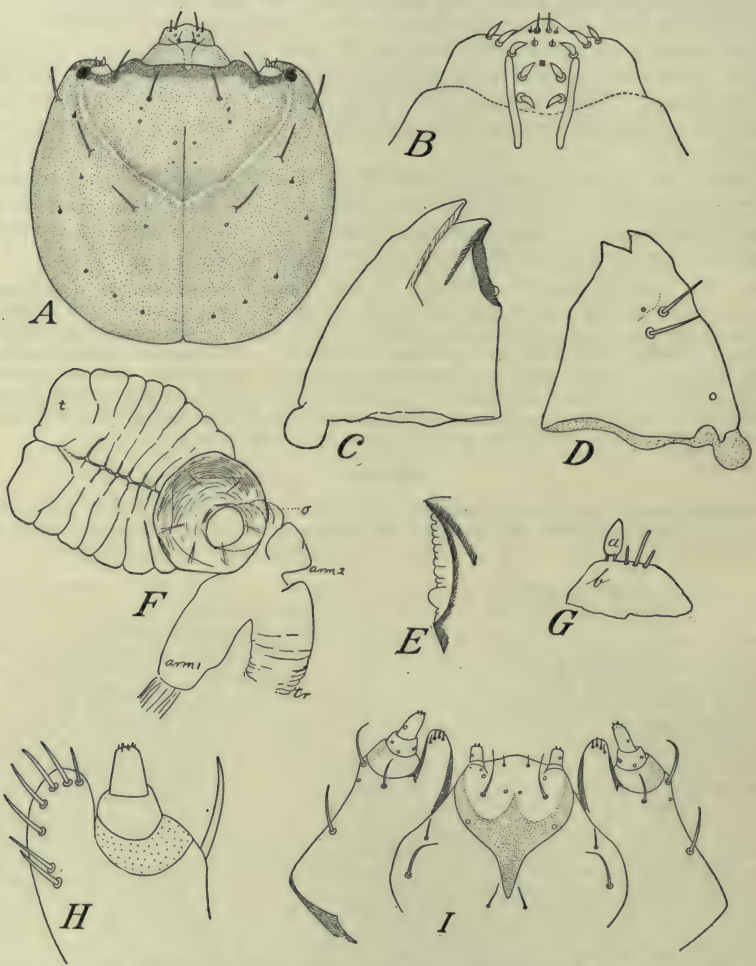

FIGURE 12.—Larval parts of *Anthonomus eugenii: A,* head capsule, dorsal view, ×72; *B,* epipharynx ×269; *C,* mandible, ventral view, ×176; *D,* mandible, dorsal view, ×145; *E,* finely crenulate margin of mandible, ×336; *F,* spiracle, ×366; *G,* antenna, ×369; *H,* maxilla and labium, ×125; *I,* maxillary lobe and palpus, ×232.

Head capsule (fig. 12, *A*) light amber, with margins, particularly anterior margin, much darker; head about as wide as long, sides rounded; epicranial and frontal sutures rather distinct; epicranial median suture about half length of cranium. Frons subtriangular, with distinct dark median line indicating carina running from posterior angle to about the middle; sutural margins irregularly sinuate; frons with 2 pairs of large setae, 3 pairs of small setae, and 1 pair of sensory spots. Ocelli large and distinct, immediately below the

antennae, 1 on each side of head. Antenna (fig. 12, *G*) two-jointed; basal joint (*b*) dome shaped and carrying 3 small tactile hairs, middle one longest and about length of apical joint; apical joint (*a*) mammilate, elongate, somewhat pointed, and with a small cylindrical ring at base. Clypeus about three times as wide as long. Labrum broadly transverse, anterior margin showing 2 lateral lobes and 1 median lobe; posterior margin prolonged into a triangular projection and covered by clypeus; on each side with 2 well-developed setae near anterior margin, 1 of similar size at posterior margin, and 1 sensory spot.

Epipharynx (fig. 12, *B*) having (1) on each side a lateral group of 3 stout, elongate-ovate, curved, apically pointed setae, outer seta narrower than others, setae arranged in oblique series; (2) near anterior margin a paramedian triangularly arranged group of 3 setae, the anterior inner seta elongate and pointed, and the other 2 small and short; (3) inside anterior end of each epipharyngeal rod 2 setae, 1 in front of the other, both stout, somewhat curved, elongate-oval, and pointed. Mandibles (fig. 12, *C* and *D*) strong, subtriangular, with broad base and heavy condyle; apex provided with an apical and a subapical tooth; facing the buccal cavity with a hollow, gouge-shaped part having margin finely crenulate (fig. 12, *E*) and limited posteriorly by a semiglobular, rather distinct denticle. Maxillae (fig. 12, *I*) with cardo and stipes of shape, proportional size, and setal armature typical of curculionid larvae. Maxillary lobe or mala (fig. 12, *H*) reaching to middle of apical joint of palpus; dorsal and ventral surfaces smooth, lightly sclerotic; dorsal surface with a longitudinal row of 7 strong, slightly curved, slender setae; ventral surface at tip with 4 minute setae. Maxillary palpus (fig. 12, *H*) extending slightly beyond mala, two-jointed; proximal joint thick, subcylindrical, almost as long as cardo, bearing on ventral side 1 seta and 2 sensory punctures; distal joint fingerlike, bearing several terminal papillae. Subfacial area entire, subdivision into mental, submental, and maxillary articulating areas not marked; on each side 3 well-developed setae. Prementum posteriorly limited by an anteriorly concave, in the middle spearlike, sclerotization; 1 seta and 2 to 4 sensory punctures on each side. Labial palpus short, two-jointed, distal joint cylindrical, three times as long as wide, with several small terminal papillae; proximal joint very short; ligula bearing 2 small setae.

PUPA
(Fig. 13)

Length 3.5 to 4 mm, width 2 mm. Uniformly white when first formed. Head of moderate size, round, and bent completely below prothoracic shield, the entire anterior free margin of which is seen in ventral view of pupa. Eye cases of moderate size and distance between them less than width of beak. Beak long and slender, reaching nearly to posterior margin of metathoracic sternum. Antennae ventrally placed, geniculate, terminally reaching to lateral margins of pupa and on level with insertion of first pair of legs. Prothoracic shield large and dome shaped dorsally. Elytra, wings, and tarsal tips of third pair of legs all terminating at sixth abdominal segment; tips of wings not covered by elytra. Ninth dorsal abdominal segment much prolonged laterally sinuate, basally broad, apically sclerotic, and narrowly deeply cleft, with the apices of lobes not divergent, as described by Pierce (*10, p. 271*). All setae yellowish brown and of moderate size, those of the prothoracic tergum somewhat larger and more prominent. Setal arrangement as follows: On each side of head 1 seta near inner margin of eye case and above it, 1 seta at base of beak, and 2 setae in front of insertion of antenna. On each side of prothoracic tergum are inserted 3 anterior, marginal setae, all arising from tubercles; 2 paramedian setae, 1 more anterior than the other, both arising from tubercles, the more anterior seta with a minute setula inside its base; and

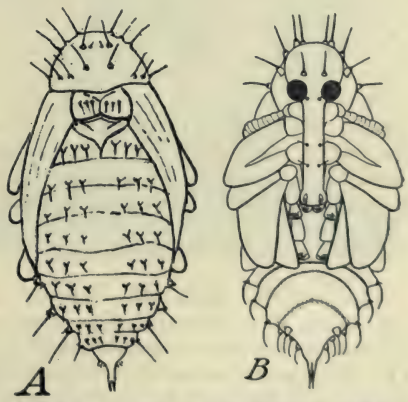

FIGURE 13.—Pupa of *Anthonomus eugenii*: *A*, dorsal view; *B*, ventral view, ×12.5.

3 setae in a transverse line exteriorly near the posterior margin, the distances between them about equal. On each side of the mesothoracic tergum are 3 small setae close together in a transverse line, and on each side of the metathoracic tergum are also 3 setae, similarly arranged in a transverse line, but larger than the corresponding mesothoracic setae and farther apart. On the abdominal segments are, on each side, 3 dorsal setae in a transverse line on the first to the eighth abdominal segments and 1 lateral seta on each pleurum of the first to the eighth abdominal segments. There are no setae on any abdominal sternum.

WEEVILS SOMETIMES MISTAKEN FOR THE PEPPER WEEVIL

Several weevils are found associated with the pepper weevil, and some of them resemble *Anthonomus eugenii* so closely that they are often mistaken for it. H. C. Fall has determined five of these weevils as follows: *A. ornatulus* Dietz, rarely found on peppers; *A. solani* Fall, occurring on nightshade; *Paragoges maculatus* Lec., occurring on sunflower and often on peppers; *Smicronyx* sp., breeding on pigweed and sometimes found on peppers; and *Desmoris constrictus* (Say), common on sunflower and often found on peppers.

FOOD HABITS

Adult weevils prefer buds and tender pods of peppers, but in the fall and winter when these are not available they feed upon the leaves, and they have been known to subsist on the bark of green stalks near the ground. They also feed upon the buds, berries, and foliage of nightshade, and on the buds, flowers, and pods of eggplant. Both male and female weevils feed by eating holes in the pods or buds. These holes are similar to the egg punctures made by the females, except that they are often considerably larger.

The larva, upon hatching from the egg, begins feeding on the surrounding tissue, confining its activity to a single bud or pod. Larvae may feed and develop in the wall of the pepper pod, but they are more often found in the seed and seed core. If the food supply becomes exhausted before normal development is complete, the larva either dies or transforms to a dwarfed adult. Adults have been observed to emerge from buds not larger than a normal weevil, in which case the weevils were unusually small.

SEASONAL ACTIVITY

The weevils spend the winter on nightshade or on such pepper plants as live through the winter. There seems to be a definite migration to and concentration upon nightshade in the fall (table 1). The weevils feed upon the nightshade foliage until the berries begin to develop, which is usually in April but may be as early as February, and then oviposit in the berries. One or two generations may develop in nightshade berries before peppers are large enough to accommodate developing larvae. In the laboratory weevils have been known to oviposit in the small blossom buds of nightshade and the eggs to develop into tiny adults. In areas where peppers are grown as a winter crop the weevils are active on them continuously, though breeding may be considerably reduced during the colder months.

TABLE 1.—*Occurrence of the pepper weevil on nightshade and pepper plants during winter and early spring* [1]

Date	Weevils on pepper plants	Weevils on nightshade plants	Date	Weevils on pepper plants	Weevils on nightshade plants
1927–28	*Number*	*Number*	1929–30	*Number*	*Number*
December	183	[2]	November	66	80
January	438	[2]	December	41	[2]
February	221	1,382	January 3	130	[2]
April 2	[3]	2,000	January 23	75	781
April 20	[3]	576			

[1] The nightshade and pepper plants from which these records were taken were in the same locality. Counts were made by beating the plants over a coarse screen with a bag beneath. Fifty pepper plants and the equivalent amount of nightshade foliage were taken as units.
[2] No count made.
[3] No pepper plants available.

Overwintering pepper plants in favorable situations may set buds throughout the winter, and the weevils may oviposit in these buds very early in the spring. In 1931 buds containing eggs and larvae were found on such plants as early as February 20 (fig. 9).

In the newly planted pepper fields the first buds begin to set when the plants are about 8 to 10 inches high (fig. 14). This may be as early as the middle of May, but is usually in June. From this time on, the plants are capable of being infested, and weevils moving from the nightshade and old pepper fields during the spring flight find these plants and oviposit in the buds. Later, when the young pods begin to develop, these also are attacked.

FIGURE 14.—Young pepper plant at time first buds are setting.

There is probably some movement back and forth between peppers and nightshade during the summer. Some weevils are present on nightshade throughout the summer, and it is probable that a portion of these remain there and oviposit in the berries throughout the year. In situations where the nightshade has become infested from adjacent pepper fields, and where no peppers were nearby the following season, weevils are known to have survived into the second fall; but since the nightshade was destroyed during the second winter, there are no data indicating how much longer they might have survived.

The relation between the period of pepper-weevil activity and that of host development is shown in figure 15.

WINTER SURVIVAL AND ITS RELATION TO THE HOST PLANTS

Adult weevils may be found on overwintering pepper plants throughout the winter. They become active on warm days, sometimes even taking flight. When the weather is cold, they crawl into protecting crevices or under dry leaves at the base of the plants. In such fields larvae and pupae could be found in green pods during the winters of 1925–26 and 1927–28, and until March of 1926 and 1928 (table 2).

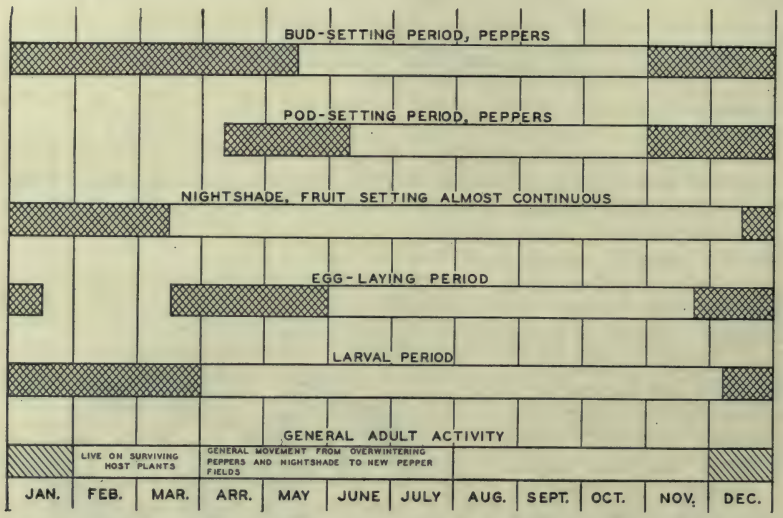

FIGURE 15.—Relation between period of pepper-weevil activity and that of host development. (Blank spaces on horizontal bars indicate period when the activity mentioned always exists. Simple hatching or shading indicates period of adult movement from peppers to nightshade. Cross-hatching indicates period when condition mentioned may or may not exist because of variations in seasonal and weather conditions.)

TABLE 2.—*Occurrence of stages of the pepper weevil on pepper plants in Orange and Los Angeles Counties, Calif., during the winter*

Date	Pods examined	Adults	Larvae	Pupae	Total, all stages
	Number	*Number*	*Number*	*Number*	*Number*
December 1924	71	31	107	99	237
January 7, 1925	98	11	10	21	42
January 29, 1925	95	0	1	2	3
November 1927	134	20	27	135	182
December 19, 1927	70	13	99	33	145
January 6, 1928	10	0	2	2	4
January 20, 1928	18	0	8	7	15
February 8, 1928	17	6	6	1	13
February 20, 1928	58	5	11	3	19
March 10, 1928	10	0	3	2	5

In the absence of overwintering pepper plants, nightshade is the only host in which the insect can survive the winter. At Norwalk, Calif., during the winter of 1927, weevils were very numerous on nightshade, 30 adults having been collected from a plant only 14 inches high. Pepper fields nearby were damaged 75 percent the following summer.

True hibernation of the pepper weevil has not been observed in southern California. During the winters of 1927–28, 1928–29, and 1929–30, experiments were undertaken to test further the possibility of hibernation. At 15-day intervals during the fall and winter 3 or 4 cages of 48-cubic-foot capacity covered with weevil-tight screen (fig. 16) were set up at the laboratory and filled to a depth of 1 foot with dry grass, leaves, cut pepper plants, dry weeds, or cornstalks, or were placed over living pepper or nightshade plants. In addition, 2 or more cages representing each of these conditions were put out in or near pepper fields each month during the winter. From 100 to 200 adult weevils collected from the field were put in each cage. The presence of weevils on the screen was noted every 4 days until the following July. Only weevils in those cages containing the living nightshade or pepper plants survived until the spring crop of plants was large enough to infest. Survival was determined

FIGURE 16.—Hibernation cages for the pepper weevil.

by examining the material in the cages or by counting the adult weevils attracted to fresh pepper plants set in the cages in June. In some of the cages that were left standing all summer, weevils continued to breed on nightshade until November. Continuous breeding was observed under field conditions during the same period.

The weevil may become inactive for short periods, and it has been known to survive for 60 days in hibernation cages without its natural host plants, although the percentage survival for this period was very low.

The relation between winter survival and the presence of host plants was tested further during the winter of 1932–33. During November and December, 25 or more weevils were placed in each of several small cages, together with green twigs of one of the host plants or of the weeds previously mentioned as being common in the locality, and in a few cages weevils were placed without food. Under normal insectary conditions no weevils survived more than 22 days without food, but at a temperature of 40° to 42° F. some weevils lived for as long as 32 days. On the nonhost plants the longest period of survival was 39 days. On the host plants, however, where suitable food was continuously available, from 4 to 20

percent of the weevils were still alive on May 1, after more than 5 months.

This experiment gives further proof that, under conditions as they exist in southern California, the pepper weevil cannot survive the winter unless pepper, nightshade, or eggplant is present, a fact that is the basis of control measures which are discussed later.

LIFE CYCLE

LONGEVITY

The pepper weevil probably lives for 3 or 4 months under natural conditions. Laboratory-reared females mated and kept for oviposition records have lived as long as 135 days, the average being 78.7 days (table 3). The males, in most cases, lived slightly longer. One female, kept on nightshade in the laboratory through the winter, lived for 316 days, and deposited fertile eggs up to a few days before her death. No weevils lived more than 150 days on pepper under summer weather conditions.

TABLE 3.—*Length of adult life and oviposition period of 25 females in the laboratory*

Date emerged	Date mated	Date first egg	Length of adult life	Length of oviposition period	Eggs deposited
1926			*Days*	*Days*	*Number*
May 16	May 19	May 22	103	95	587
May 17		---do----	58	53	403
May 23		May 29	128	121	418
May 28	June 3	June 6	110	97	382
Do	---do----	---do----	56	46	192
June 4	June 8	June 12	93	79	192
June 7	June 9	June 11	88	84	590
June 9	June 14	June 15	21	16	72
June 13	June 15	June 19	135	129	584
Do	---do----	June 17	116	112	413
June 14	June 14	---do----	24	21	66
June 20	June 22	June 24	24	21	112
July 15	July 21	July 25	28	19	74
1927					
July 18	July 18	July 22	83	79	372
July 20	July 22	July 24	93	89	444
Do	July 21	July 25	91	87	634
Do	---do----	July 26	122	105	546
July 21	July 22	July 24	75	72	328
July 25	July 27	July 28	91	88	335
Do	---do----	---do----	59	56	281
Aug. 13	Aug. 16	Aug. 18	114	109	503
Aug. 19	Aug. 25	Aug. 27	66	58	402
Do	---do----	---do----	66	58	336
Sept. 11	Sept. 20	Sept. 23	85	76	231
Sept. 16	---do----	Sept. 21	39	34	28
Average			78.7	72.2	341
Average number of eggs laid per day per female					4.7

MATING

Mating usually takes place about 2 days after emergence and may be repeated several times. The males are very active, and one male is capable of fertilizing a number of females. One mating is sufficient to insure fertility of the female during her entire life.

OVIPOSITION

The interval between mating and oviposition is usually not more than 2 days in midsummer, but it may be as long as 8 days early in the spring or in the fall.

The eggs are laid singly beneath the surface of the bud or pod at varying depths or, rarely, on the surface. The usual place of oviposition, in the case of the bud, is in an anther, where the newly hatched larva has easy access to the immature pollen as its first food. In the case of the pod, the egg may be placed anywhere inside the wall of the fruit or, in the thicker walled varieties, in the wall itself.

Before depositing an egg the female walks around over the bud or pod to select a suitable spot. She makes a puncture by pushing in first one mandible and then another, and then inserts the beak, usually to the eyes, and enlarges the cavity. The hole prepared, she deposits an egg and covers the puncture with a clear, light yellow fluid, which soon hardens, sealing the hole, and turns brown and finally black. The whole operation normally takes from 2 to 4 minutes.

The length of the oviposition period and the number of eggs deposited by 25 females in the laboratory are shown in table 3. Occasionally a female will deposit 20 or more eggs in 48 hours.

Egg counts were obtained in the laboratory by supplying females with sprigs of buds or pods in which to oviposit. Every other day fresh material was placed in the cage and the old material was removed for examination. Buds and pods that were found to be punctured were opened and examined for eggs.

Temperature is probably the principal controlling factor in oviposition. Ovulation ceases in most females during the winter, probably very soon after the first frosts, when there are no longer any pepper buds or pods or nightshade berries in which to oviposit. During the winter of 1927–28 and the spring and fall of 1928 a number of weevils were collected in the field and the females dissected. Of females collected during the winter and early spring, very few showed any development of the ovaries. A few, however, were shown to be capable of laying eggs throughout the winter. Ovulation and oviposition were resumed in the spring, as soon as pepper buds or nightshade berries were available. Experiments both in the greenhouse and in the insectary in March and April showed that a temperature of 60° F. sustained for 4 or 5 days will cause the ovaries to develop, even when there is no material in which to oviposit. When pepper buds or nightshade berries are placed in the cage, they act as a stimulating factor at lower temperatures. The presence of male weevils seems to act as an inhibiting factor. In San Diego County, where the average temperature is somewhat higher than in Orange and Los Angeles Counties, development continues throughout the winter, eggs and immature stages having been found at all seasons.

INCUBATION PERIOD

The duration of the incubation period was determined by placing fertile females on pods, allowing them to remain for an hour, and

beginning with the third day thereafter making frequent examinations of the pods until newly hatched larvae were found. This period was found to be from 3 to 5 days, with an average of 4.3 days.

A day or so before the egg hatches, the mandibles become visible through the eggshell as two brown spots, and, as the time of hatching approaches, the larva may also be seen.

LARVAL DEVELOPMENT

The newly hatched larva measures from 0.8 to 1.5 mm in length, averaging 1 mm. The head is disproportionately large, almost white, and the mandibles are dark brown, tipped with black. The body is shining white. Feeding is begun within 1 to 4 hours after hatching, depending on the temperature. If in a pod, the larva usually works its way into the mass of young seeds; if in a bud, it feeds on the immature pollen. The first molt occurs when the larva is 1 to 4 days old, or an average of 1.7 days.

Immediately after molting the larva swells, becoming from 1.3 to 2.6 mm, or an average of 1.9 mm, long. The head is light yellow, still disproportionately large, and the mandibles are dark brown or black. The larva continues feeding until ready for the second molt, which takes place from 1 to 5 days, or an average of 2.2 days, after the first. A very incomplete cell is sometimes constructed in which the larva undergoes this molt.

Shortly after the second molt the larva is from 2.2 to 5 mm in length, averaging 3.3 mm. Feeding is resumed and continued for from 1 to 7 days, averaging 3.5 days.

The third-stage larva forms a pupal cell by excavating an oval cavity and lining it with excrement, probably supplemented by a secretion from the anal glands. This material is taken in the mandibles from the anus and plastered on the walls of the cavity, where it is subsequently smoothed by the movements of the larva. It soon hardens, becoming strong, though rather brittle. When the cell is finished, the larva rests awhile and the body becomes shorter and greater in diameter. The contents of the intestines having been voided, the larva is shining, semiopaque white. The prepupal stage lasts from 1 to 8 days, averaging 4.9 days.

The larvae are sensitive to light and especially to the outside air. When a pod is opened, they burrow down among the seeds and into the placenta of the pod. They are pugnacious at all times, biting at anything that disturbs them, frequently even attacking and devouring one another. During the prepupal period the larvae keep the pupal cells closed, and if these are opened for observation they are repaired at once.

DEVELOPMENT WITHIN THE PUPAL CELL

When first formed, the pupa is shining, semitransparent, and white. The tip of the abdomen rests upon a cushion of the cast-off larval skin. A few hours after pupation the eye spots begin to show a light yellow tinge. After 2 or 3 days the eyes become dark, the beak light yellowish brown near the apex and black at the tip, and the apical half of the elytra and apical joints of the antenna dark gray. The pupal stage lasts from 3 to 6 days, averaging 4.7 days.

EMERGENCE OF THE ADULT

When it reaches the adult stage, the pepper weevil is light brown. It usually remains in the pupal cell for several hours until it becomes fully colored and active. From 3 hours to 4 days may elapse before it emerges from the pod or bud. The buds, having a thin outer coating, offer little resistance to the weevil's emergence, whereas more effort is required to penetrate the tougher skin of the pepper pods. In emerging from the pod or bud the weevil cuts a clean, round hole. Feeding begins immediately after emergence, preferably upon the buds or tender pods.

SEX RATIO

Observations were made during every month of the year on 3,016 weevils. The percentage of males ranged from 45.3 in October to 72.9 in April, being higher than the percentage of females in nearly all months.

TOTAL TIME OF DEVELOPMENT

The total time of development from egg to adult during the summer, as determined by laboratory experiments, ranged from 16 to 23 days, the average being 20.9 days. If the time between emergence and oviposition is added, a complete generation from first egg to first egg during the summer averages about 25 days.

Over the entire active season, which is from the middle of April to the last of October, the length of a complete generation varies, being from 22 to 46 days, with an average of 32.1 days (table 4).

TABLE 4.—*Length of time required for development from egg to adult and from egg to egg*

Date egg laid	Total period egg to adult	Total period egg to first egg	Date egg laid	Total period egg to adult	Total period egg to first egg
	Days	*Days*		*Days*	*Days*
Apr. 15, 1928	38	43	Aug. 12, 1926	18	22
Apr. 22, 1926	23	31	Aug. 20, 1927	22	32
Apr. 24, 1926	23	29	Aug. 21, 1927	26	32
May 20, 1926	24	29	Aug. 28, 1927	25	29
May 27, 1926	22	28	Sept. 15, 1927	25	33
May 27, 1926	24	28	Sept. 20, 1927	26	34
May 28, 1928	24	31	Sept. 23, 1927	23	32
June 23, 1926	26	35	Sept. 27, 1927	32	39
June 28, 1928	22	28	Oct. 27, 1927	36	46
July 21, 1927	24	28	Oct. 28, 1927	36	46
July 22, 1927	28	35			
July 23, 1927	21	26	Average	25.5	32.1
July 23, 1927	23	26			
July 26, 1927	24	31	Minimum	18	22
July 26, 1928	24	30	Maximum	38	46

Table 5 gives the duration of the various stages of 11 pepper weevils reared in the laboratory during the summer.

Such factors as excessive dryness and excessive moisture tend to retard, and in some cases prevent, development. During the hot weather infested buds are especially subject to drying, and pods that fall to the ground and lie exposed to the sun often become dry before the weevil can complete its development. Pratt (*12*) mentions the rotting of the pods as a factor in control. There is no doubt that

there is some mortality from this cause where irrigation is practiced, because the fallen pods are washed to the lower end of the row where the excessive moisture causes them to rot quickly (fig. 5). Larvae that are fully grown, however, have been known to complete development even in completely decayed pods.

TABLE 5.—*Duration of stages of 11 pepper weevils reared in the laboratory*

Date egg laid	Egg stage	First instar	Second instar	Third instar	Prepupal stage	Pupal stage	Period from formation of adult to emergence from host	Total period of development
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
July 6	5	1	2	2	6	5	1	22
Do	3	2			6	5	2	22
Do	3	2			6	5	1	21
Do	4	2			6	6	1	23
Do	4	2		2	8			23
July 12	4	1	3	5	2	4	1	20
Do	4	2	2	3	4	4	1	20
July 19	5	1	2	4	1	4	0	17
Aug. 2	5			2	5	5	2	23
Do	5	1			3	5	0	19
Aug. 4	5	2	2	3	4	3	2	21

NUMBER OF GENERATIONS

The number of generations varies according to the season. Observations in the insectary showed, in 1926, a maximum of 8 generations (data from 52 pairs); in 1927, only 5 generations and a partial sixth (data from 45 pairs); in 1928, 7 and a partial eighth (data from 32 pairs); and in 1929, a maximum of 7 generations (data from 18 pairs). The minimum number of generations is 2 or 3, owing to the long life of the adults. In San Diego County, where peppers are grown all the year, weevil development may be continuous.

There is considerable overlapping of generations under field conditions. Overwintering adults may live until midsummer, and adults of the first generation have been known to remain active the entire season.

NATURAL ENEMIES

Parasites of the pepper weevil listed by Pierce, Cushman, and Hood (*11*) include *Pediculoides ventricosus* Newport, *Catolaccus hunteri* Crawford, and *Bracon mellitor* Say. In California at least two undetermined hymenopterous parasites were found to be very common in 1928. These attacked the weevil larvae in pepper buds as external parasites, but they have never been found attacking them in the pepper pods. In a few cases an undetermined mite has been found on the bodies of the adults.

CONTROL MEASURES

INSECTICIDES

Numerous experiments carried out over a period of 5 years showed that calcium arsenate in dust form applied at the rate of 8 to 10 pounds per acre at intervals of 5 to 7 days was the most satisfactory insecticide for controlling the pepper weevil. The use of this mate-

rial is objectionable, however, because of the necessity of removing the arsenical residue before the peppers are sold. Moreover, its continued use, especially if started early, may favor an aphid infestation (*7*). Various fluorine dusts, including sodium fluoaluminate (synthetic cryolite), potassium fluoaluminate, and barium fluosilicate, were even more toxic to the pepper weevil than calcium arsenate, but they all caused plant injury and reduction in yield (*6*). Because of complications of this kind, control investigations are being continued.

DESTRUCTION OF HOST PLANTS

Inasmuch as the pepper weevil has been found to survive the winter only on pepper or nightshade plants, and early infestations have usually been traced to overwintering pepper plants or to nightshade nearby, it was believed that the insect could be controlled if the host plants were destroyed.

A campaign was therefore undertaken in Orange County, Calif., to have growers disk and plow their pepper fields soon after harvest was completed, in any case not later than January 15, and in addition to destroy all nightshade plants along fences, roads, ditch banks, around sheds, and so forth. For 3 years wherever this practice has been fairly faithfully carried out no serious general infestation has occurred. Infestations of damaging proportions have, in most cases, been traced to undestroyed nightshade.

In view of these results and also of the difficulties in the use of arsenical and fluorine insecticides, cultural control by the destruction of old pepper fields and nightshade plants during the winter is the best remedy now known for keeping the pepper weevil in check.

SUMMARY

The pepper weevil causes serious damage to peppers in the Southwest, especially in California, Texas, and New Mexico. It is well distributed over the pepper-growing areas of southern California, southern New Mexico, and southeastern Texas, and occurs also in Arizona, Mexico, and the island of Oahu, Hawaii. It was described from Mexico in 1894, made its first appearance in the United States in Texas in 1904, in California in 1923, and in Hawaii in 1933.

The host plants are confined exclusively to varieties of pepper, nightshade, and eggplant.

Damage from pepper-weevil attack is from destruction of blossom buds and immature pods.

Dissemination is accomplished by flight of the insect and transportation of infested material. Newly planted pepper fields become infested either from overwintering nightshade or from old pepper fields. The degree of infestation increases in proportion to the number of weevils entering the field. An infestation spreads gradually and may or may not be uniform over the field.

The adult and immature stages of the pepper weevil are described.

Adults feed on buds or tender pods of the pepper, but when these are not available they feed on tender foliage. They feed also on nightshade berries and foliage. Larvae feed on the contents of the bud or pod, or in the pod wall, of the pepper.

Adult weevils spend the winter on nightshade or old pepper plants, being active on warm days. A true hibernation has not been observed in California, and in order for the weevils to survive the winter one of its host plants must be present. Migration to pepper fields begins in May or June at about the time the first buds form. Some weevils continue to breed on nightshade.

The adult lives for 2 or 3 months in the summer, but overwintering individuals may live as long as 10 months.

Mating occurs soon after adult emergence, and oviposition begins from 2 to 8 days later. The eggs are laid singly in pepper buds or pods.

In the laboratory the oviposition period ranged from 16 to 129 days, and during this time from 28 to 634 eggs were laid. Temperature directly affects ovulation and oviposition. Growth is rapid, the total time of development from egg to adult being 16 to 23 days in the summer and 22 to 46 days in the spring and fall. All stages except the adult stage are passed within the bud or pod. The adult emerges from the pod by cutting a clean round hole. The proportion of males ranged from 45 to 72 percent, usually with an excess of males.

In different years maxima of 5 to 8 generations were found.

Natural enemies are of little importance in checking a pepper-weevil infestation.

Calcium arsenate gave satisfactory control, but this material cannot be recommended because of the possibility of an arsenical residue. All fluorine dusts caused plant injury. Destruction of all pepper plants after harvest and cleaning up of nightshade plants in the vicinity proved to be the best method of keeping the pepper weevil in check.

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TECHNICAL BULLETIN No. 446 MARCH 1935

YIELDS OF BARLEY IN THE UNITED STATES AND CANADA 1927-31

By

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D.C.

YIELDS OF BARLEY IN THE UNITED STATES AND CANADA, 1927–31

By H. V. HARLAN, *principal agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry;* P. RUSSELL COWAN, *cerealist, Dominion of Canada Experimental Farms;* and LUCILLE REINBACH, *junior agricultural statistician, Division of Cereal Crops and Diseases, Bureau of Plant Industry*

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INTRODUCTION

GENERAL

This bulletin reports the yields of barley secured on the testing fields of the United States and Canada during the 5 years, 1927–31. The bringing of these results together essentially doubles the value of the tests on both sides of the boundary. Many farmers in the United States are operating farms located in sections better served by nearby Canadian stations than by their own, where these are distant. The converse is also true.

The textual matter has been reduced greatly beyond that of former publications for reasons of economy in printing.

Percentage comparisons have been made to facilitate the use of the data. These percentages are calculated on the total yields of the varieties for the years grown. While this is highly accurate, it is not always identical with results that would have been secured by the use of average yields.

During these 5 years there has been an increase in the use of row tests at the expense of plot tests.

As far as possible local recommendations have been included as to varieties and rate and date of seeding. It is thought that this inclusion will add to the value of the bulletin.

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As in previous reports, the data are contributions of many agencies, and the Division of Cereal Crops and Diseases has acted only as an agency for compilation and for calculating the averages and percentages. It is believed that nothing has been included in the discussion of any station that has not had the approval of those in charge of that station.

CANADA

The bulk of the data from Canada consists of results obtained by the Dominion Experimental Farms. This is, of course, an extensive testing agency, and responsibility for the presentation of the results has been accepted by P. Russell Cowan as an author of this bulletin. This, naturally, will not be taken to mean that the material from the independent provincial agencies in Canada is not on an absolutely equal footing in authorship, but only that, due to the number of stations, the task of preparing the material from the Dominion Experimental Farms has been a little more onerous.

Most of the Canadian results have been secured from replicated rows. At the stations under the direction of the Dominion Experimental Farms the plan of 4 series of 5 rod-row blocks to a variety was used. These 5 rod rows, sown 7 or 10 inches apart, are reduced to 3 at harvest time, the yields of the 3 being considered as the yield of a plot. The only exception is at Fort Vermilion, where yields are reported from four 1/100-acre plots.

At the University of Alberta the tests were conducted in 4 series of 3 rod-row blocks, with rows 12 inches apart, the center rows of which were harvested. The yield, therefore, represents an average of 4 center rows.

The tests at MacDonald College were conducted in 1/100-acre plots with varying numbers of replications and those at the Ontario Agricultural College in triplicated plots.

At the University of Saskatchewan the tests were made in groups of 6 replicates, consisting of 3 rod rows each, of which the center rows in each case were harvested. The arrangement of the 3-row groups was in accordance with the Latin-square system.

RESULTS BY STATIONS

ARIZONA

Varietal tests of barley were conducted at two points in Arizona during the period 1927–31. Results at the Salt River Valley Farm, Mesa, Ariz., are reported by I. A. Briggs, of the Agricultural Experiment Station at Tucson. The plot tests of barley at the United States Field Station, Sacaton, were made by the Division of Cotton, Rubber, and Other Tropical Plants.

SALT RIVER VALLEY FARM, MESA

I. A. Briggs, *associate agronomist*

The leading varieties in the yield test at Mesa are Common Six-Row, Trebi, Club Mariout, and Sacramento. The yield of Sacramento has been high, but it is rather late to fit well into the cereal program where summer cropping of small-grain land is practiced. Club Mariout produced a slightly higher yield than Common Six-Row in the previous 5-year period (1922–26), but it yielded decidedly less in the years

reported in table 1, as well as in the combined period of 10 years (1922–31). There has been little difference between the yields of Trebi and Common Six-Row. Common Six-Row and Sacramento are recommended for southern Arizona, the latter variety being favored on rich lands where strength of straw is important. Trebi is recommended for elevations above 3,500 feet.

For pasture purposes, for which much of the barley is used, the seed should be sown as early in the fall as danger from hot weather is past. This is not earlier than September 25 for the Salt River Valley. For elevations of 7,000 feet, sowings should be made from April 15 to May 15. Sixty pounds per acre for grain purposes is recommended for midseason sowings and 90 pounds when barley is wanted for winter pasture.

TABLE 1.—*Acre yields of varieties of barley grown at the Salt River Valley Farm, Mesa, Ariz., and at the United States Field Station, Sacaton, Ariz., in 1 or more of the years 1927–31*

[Data for Mesa obtained through the courtesy of the Arizona Agricultural Experiment Station and for Sacaton through the courtesy of the Division of Cotton, Rubber, and Other Tropical Plants]

Station and variety	C.I. no.[1]	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Percent*
Mesa:														
Common Six-Row	4625	1	33.7	6	76.8	6	60.2	3	88.7	4	70.5	66.0	5	101.0
Trebi [2]	936	1	42.1	3	65.7	3	59.5	3	71.3	4	88.1	65.3	5	100.0
Beardless	4627	1	49.2	3	53.9	3	54.7	3	67.4	4	67.6	58.6	5	89.6
Club Mariout	261	1	36.1	3	62.5	3	61.8	3	68.0	3	67.3	59.1	5	90.5
Sacramento	4108	----	------	3	78.4	3	66.1	3	79.7	8	79.7	------	4	106.8
White Smyrna	195	----	------	3	49.4	3	55.8	3	77.3	----	------	------	3	92.9
Coast	690	----	------	----	------	3	62.1	----	------	----	------	------	1	104.4
Sacaton:														
Coast	690	4	38.2	----	------	2	65.1	7	63.7	1	55.3	------	4	118.4
Club Mariout	261	4	39.5	1	32.7	1	69.6	7	57.6	1	55.3	50.9	5	120.9
Trebi [2]	936	4	42.2	1	22.9	1	41.6	4	58.5	1	45.5	42.1	5	100.0
Orel	351	4	25.5	1	23.4	1	34.8	3	30.7	1	32.8	29.4	5	69.9
Peruvian	935	4	47.0	1	60.5	----	------	----	------	----	------	------	2	165.1
Hero	1286	4	47.0	----	------	2	71.8	7	54.3	1	60.7	------	4	124.5
Meloy	1176	3	36.1	----	------	----	------	----	------	----	------	------	1	85.5
Sandrel	937	3	45.0	----	------	----	------	----	------	----	------	------	1	106.6
Wisconsin Winter	2159	3	12.5	----	------	----	------	----	------	----	------	------	1	29.6
Vaughn	1367	----	------	2	56.3	6	66.1	1	58.8	----	------	------	3	147.3

[1] Serial accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

[2] Standard variety with which others are compared.

UNITED STATES FIELD STATION, SACATON

C. J. KING, *agronomist and superintendent*

The leading varieties at Sacaton are similar to those at Mesa. Vaughn, Club Mariout, Coast, and Trebi are recommended. These recommendations are based on a combination of yields and observations. Vaughn is by all odds the most promising. It is stiff-strawed and produces high yields. Although the yield of Hero reported in table 1 is very good, it is considered too late for general seeding.

ARKANSAS

AGRICULTURAL EXPERIMENT STATION, FAYETTEVILLE

C. K. McClelland, *assistant agronomist*

Barley is an unimportant crop in Arkansas. Varieties have been grown at Fayetteville simply to secure definite information on the possibilities of the crop. As shown in table 2, there are occasional years in which the crop is destroyed by freezing. However, most of the winter varieties grown have produced fair yields. There was a variation of only 35 percent in the average yield of the varieties grown in all 5 years. Selection 6 (C.I. 4678)[1], secured from the Kentucky Agricultural Experiment Station, produced the highest average yield. Several other varieties were of almost equal promise.

These results are quite in accord with those secured in 1924, 1925, and 1926. Previous to 1926 experiments with spring varieties showed that spring seeding was not advisable. The most favorable time for seeding is the first week in October. The most satisfactory rate of seeding is 7 pecks per acre.

TABLE 2.—*Acre yields of varieties of barley grown at the Arkansas Agricultural Experiment Station, Fayetteville, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Arkansas Agricultural Experiment Station]

Variety	C.I. no.	Number of plots and acre yield										Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928 [1]		1929		1930		1931		Average yield, 1927–31		
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Percent*
Kentucky winter (commercial)	4641	1	16.3	1	0	1	18.2	1	30.9	1	36.1	20.3	5	77.5
Alaska (B.P.I.[2])	4106	1	13.8	1	0	1	13.2	1	29.8	1	43.0	20.0	5	76.2
Tennessee Winter Selection 47	3542	1	18.1	1	0	1	21.5	1	36.1	---	---	---	4	94.7
Tennessee Winter Selection 52	3543	1	17.5	1	0	1	16.0	1	24.1	1	49.3	21.4	5	81.7
Tennessee Winter Selection 57	3544	1	20.6	1	0	1	25.9	1	25.2	1	38.4	22.0	5	84.1
Tennessee Winter Selection 61	3545	1	15.0	1	0	1	29.2	1	26.9	1	56.7	25.6	5	97.6
Orel (B.P.I.)[3]	351	1	12.5	1	0	1	33.6	1	33.8	1	51.0	26.2	5	100.0
Tenkow (B.P.I.)	646	1	13.8	1	0	1	23.7	1	34.4	1	51.0	24.6	5	93.9
Selection 6 (Ky. Expt. Sta.)	4678	1	13.8	1	0	1	24.2	1	35.5	1	66.5	28.0	5	107.0
Beardless 6 (hooded)	2746	1	9.8	1	0	1	25.9	1	21.8	1	36.7	18.8	5	72.0
Kentucky 36 (Ky. Expt. Sta.)	4677	1	20.0	1	0	1	25.9	1	28.7	1	60.7	27.1	5	103.4
Union Winter (Ky. Expt. Sta.)	583	1	17.5	1	0	1	38.5	1	30.9	1	51.6	27.7	5	105.8
Wisconsin Winter (B.P.I.)	2159	1	16.9	1	0	1	34.7	---	---	---	---	---	3	111.9

[1] Crop for 1928 was destroyed by freezing.
[2] B.P.I. = Bureau of Plant Industry.
[3] Standard variety with which others are compared.

CALIFORNIA

UNIVERSITY FARM, DAVIS

B. A. Madson, *head, Agronomy Division, College of Agriculture*

The results at Davis for the years 1927–31 are not fully in accord with the long-time trends. Club Mariout, for instance, is a much better variety than shown by the data in table 3. On the other hand, Vaughn (C.I. 1367) has been a leading variety since its introduction,

[1] Accession number of Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

and it has been well to the front during the period stated. Sacramento and Atlas ranked next to Vaughn.

Due to the fact that Vaughn is difficult to thresh without fraying, Atlas is recommended for the production of malting barley. Where the seeding cannot be done until late, Club Mariout is suggested. The best time to seed is from late October until mid-January. Some seeding is done as late as March. Where a drill is used, 70 to 90 pounds per acre is sufficient. Where the grain is broadcast, the rate is increased 25 percent.

TABLE 3.—*Acre yields of varieties of barley grown at University Farm, Davis, Calif. in 1 or more of the years 1927–31*

[Data obtained in cooperation with the California Agricultural Experiment Station]

Variety	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Vaughn [1]	1367	5	86.2	5	81.5	5	63.3	5	112.3	5	54.4	79.5	5	100.0
Atlas	4118	5	81.2	5	58.8	5	62.7	5	103.8	5	50.2	71.3	5	89.7
Coast	4633	5	68.1	4	62.7	5	52.7	5	84.6	5	41.6	61.9	5	77.9
Sacramento	4108	5	82.1	5	80.8	5	48.8	5	123.1	5	28.7	72.7	5	91.4
Hero (1286–1)	4602	5	68.8	5	52.9	5	22.7	3	101.0	5	51.8	59.4	5	74.7
Club Mariout	261	5	67.4	5	46.2	5	31.6	5	75.0	5	39.1	51.9	5	65.2
Coast	690	5	67.2	5	63.1	5	52.1	5	90.6	5	43.8	63.4	5	79.7
Archer	1031	2	[2] 66.7	5	66.8	5	46.2	5	94.4				3	80.7
Mechanical Mixture	4115	2	[2] 67.3	2	[2] 51.6									
Composite Cross	4116	2	[2] 61.8	2	[2] 53.7	2	[2] 53.7	2	[2] 83.9					
Vaughn (1367–2)	5948			2	[2] 74.0	5	59.8	5	115.0				2	99.5
Vaughn (1367–1)	5947			2	[2] 67.5	5	66.5	5	113.3				2	102.4
Coast (268B)	4119			2	[2] 60.7									
Blanco (Tennessee Winter × Hero 30–3)	5045			5	73.7	5	41.0	5	96.7	5	46.8		4	82.9
Paso (Sacramento × Hero 27–1–563)	5047			2	[2] 73.8	5	50.4	5	113.1	5	32.0		3	85.0
Oso (Sacramento × California Mariout M21B2–7M)	5046			2	[2] 76.1	2	[2] 57.3	2	[2] 120.9					
Tennessee Winter	257			2	[2] 32.8	2	[2] 37.5	2	[2] 60.4					
Chevalier	278					2	[2] 46.9	2	[2] 84.4					
California Mariout	1455							2	[2] 104.2					

[1] Standard variety with which others are compared.
[2] Grown only in duplicate, not comparable, so not included in average.

COLORADO

AGRICULTURAL EXPERIMENT STATION, FORT COLLINS

ALVIN KEZER, *agronomist*, and D. W. ROBERTSON, *associate agronomist*

Although the tests at Fort Collins and Fort Lewis were made in nursery plots of 10 series of 3-row blocks, the center rows in each series being harvested, the results clearly show the superiority of Trebi in the production of grain. Hannchen is the only variety grown for the entire period that approached Trebi in yield, and at Fort Collins its 5-year average was more than 7 bushels less than that of Trebi. Trebi is, therefore, recommended for growing under irrigation. When used

as a nurse crop, however, Colsess is recommended. Colsess is stiff-strawed and much less likely to lodge and smother the alfalfa and clover. Under irrigation, 90 pounds per acre is a good seeding rate. The date of seeding varies from the first 20 days of April around Fort Collins to the last week in April around Fort Lewis.

Dry-land experiments have been carried on at Akron. As at all places of limited rainfall, the rank of varieties arranged as to yield varies much from year to year. Over a period of years, however, Blackhull, White Smyrna (Vance, C.I. 4585), Coast (C.I. 690), and Club Mariout have maintained a high average position. Several of the smooth-awned types have done well since their introduction, and it will be noted in table 4 that Flynn is almost the equal of Club Mariout in yield. Club Mariout and Flynn are recommended to farmers. Vance (White Smyrna) should have a place where combines are used. The seeding should be done in late March or early April at the rate of 4 pecks per acre.

TABLE 4.—*Acre yields of varieties of barley grown at the Colorado Agricultural Experiment Station, Fort Collins, at the Fort Lewis Farm, and at the United States Dry Land Field Station, Akron, Colo., in 1 or more of the years 1927–31*

[Data for Fort Collins and Fort Lewis obtained through the courtesy of the Colorado Agricultural Experiment Station and for Akron in cooperation with the Colorado Agricultural Experiment Station and the Division of Dry Land Agriculture]

Station and variety	C.I. no.	Station no.	Number of plots and acre yield										Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931		Average yield, 1927–31		
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Fort Collins:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Hanna	2784		10	69.1	10	60.9	10	80.6	10	87.7	10	54.8	70.6	5	83.3
Coast	2785		10	64.2	10	85.7	10	57.6						3	83.9
Gold	1145		10	58.2	10	37.6								2	56.9
Colsess	2792		10	73.3	10	90.5	10	64.2	10	90.1	10	51.7	74.0	5	87.3
Hanna	2788		10	70.6										1	81.3
Charlottetown 80	2732		10	63.9	10	46.1								2	65.3
Silver King	890		10	71.8	10	73.0								2	86.0
Telli	194		10	76.4	10	77.1								2	91.2
Nepal	595		10	51.3	10	50.0	10	55.5	10	63.8	10	45.8	53.3	5	62.9
Coast	2791		10	71.5	10	82.2	10	65.1	10	88.8	10	42.4	70.0	5	82.6
O.A.C. 21	1470		10	81.6	10	75.9	10	60.4						3	88.1
Manchuria	2783		10	79.2	10	65.6	10	66.2						3	85.3
Moister	2799	2286	10	72.3	10	82.6	10	66.4						3	89.5
Elfry	2800	2287	10	78.8	10	83.3	10	66.7	10	96.8	10	62.9	77.7	5	91.7
Canadian Thorpe	740		10	84.3	10	77.2	10	69.5	10	78.1				4	89.0
Svansota	1907		10	74.3	10	66.9	10	56.4						3	79.9
Lion	923		10	72.4	10	75.0	10	77.7						3	91.0
Hannchen	531		10	72.5	10	74.5	10	85.3	10	92.6	10	65.8	78.1	5	92.2
Trebi [1]	936	307	10	86.8	10	81.6	10	79.0	10	100.0	10	76.4	84.8	5	100.0
Club Mariout	261	335	10	76.7	10	96.6	10	59.1						3	93.9
Smyrna	2642		10	65.1	10	65.8								2	77.7
Himalaya	620		10	66.5	10	64.0	10	47.2	10	65.9	10	43.2	57.4	5	67.7
Velvet	4252		10	78.3	10	71.4	10	71.3	10	84.3	10	58.3	72.7	5	85.8
Black Six-Row	4691	319	10	61.4										1	70.7
Comfort	4578	336	10	77.7	10	70.0	10	78.2	10	84.1	10	57.4	73.5	5	86.7
Faust	4579	1084	10	69.1	10	63.6	10	51.2	10	70.3	10	48.1	60.5	5	71.3
Glabron	4577				10	72.3	10	74.8	10	83.6	10	61.0		4	86.6
Spartan	5027	1085			10	88.8	10	66.8	10	82.4	10	59.4		4	88.2
Hanna	2787				10	65.0								1	79.7
Atlas	4118	1094					10	72.1	10	107.5	10	60.2		3	93.9

[1] Standard variety with which others are compared.

TABLE 4.—*Acre yields of varieties of barley grown at the Colorado Agricultural Experiment Station, Fort Collins, at the Fort Lewis Farm, and at the United States Dry Land Field Station, Akron, Colo., in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	Station no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		Bu.		Bu.		Bu.		Bu.	Bu.		Pct.
Fort Collins—Contd.															
Dryland (smooth awn)	5673	1065					10	65.0	10	94.4	10	60.6		3	86.1
Hero	1286						10	67.4	10	90.6	10	45.8		3	79.8
Pearl	5678	1111					10	70.3	10	94.0	10	57.7		3	86.9
Arequipa	1256						10	67.4	10	86.3	10	42.3		3	76.7
Ezond	5064	1112							10	102.3	10	74.3		2	100.1
Victory	5077	1101							10	104.5	10	63.3		2	95.1
Fort Lewis:															
Coast	2791		10	92.4	10	53.3		(2)	10	64.9	10	84.8	73.9	4	85.2
Colsess	2792		10	83.7	10	52.7		(2)	10	73.2	10	67.9	69.4	4	80.0
Chevalier II	200		10	74.1	10	61.3		(2)	10	72.7	10	85.5	73.4	4	84.7
Moister	2799	2286	10	66.7	10	42.3		(2)						2	66.7
Gold	1145		10	52.3				(2)						1	50.6
O.A.C. 21	1470		10	72.5				(2)						1	70.2
Success	507		10	67.2				(2)						1	65.1
Nepal	595		10	76.1	10	43.8		(2)	10	48.7	10	57.3	56.5	4	65.1
Trebi [1]	936	307	10	103.3	10	60.0		(2)	10	94.8	10	88.7	86.7	4	100.0
Velvet	4252		10	85.2	10	49.0		(2)	10	80.8	10	76.9	73.0	4	84.2
Comfort	4578	336			10	45.0		(2)	10	64.2	10	68.5		3	73.0
Faust	4579	1084			10	53.9		(2)	10	49.9	10	61.4		3	67.8
Glabron	4577				10	45.2		(2)	10	63.3	10	69.7		3	73.2
Spartan	5027	1085			10	50.5		(2)	10	55.7	10	72.5		3	73.4
Himalaya	620				10	26.1		(2)	10	27.1				2	34.4
Elfry	2800	2287			10	43.6		(2)						1	72.7
Arequipa	1256							(2)	10	71.3	10	92.0		2	89.0
Akron:															
Blackhull [1]	878		4	28.8	4	[3]40.7	4	12.1	4	18.6	4	7.3	21.5	5	100.0
Smyrna	2642		4	27.3	4	41.9	4	11.4	4	13.2				4	93.6
Club Mariout	261	335	4	33.0	4	48.2	4	15.8	4	21.8	4	9.2	25.6	5	119.1
California Mariout	1455	314	4	16.4	4	30.8								2	67.9
Flynn	1311		4	31.5	4	44.2	4	17.7	4	16.9	4	11.4	24.3	5	113.2
White Smyrna	4587	02WS	4	23.5										1	81.6
Vance (White Smyrna)	4585	05WS	4	35.2	4	49.2	4	13.7	4	18.2	4	9.1	25.1	5	116.7
White Smyrna	4584	09WS	4	34.4	4	45.5	4	12.4	4	16.4				4	108.5
Do	4586	013WS	4	31.6										1	109.7
Coast	690		4	31.4	4	48.1	4	9.4	4	14.9	4	11.0	23.0	5	106.8
Moister	2799	2286	4	29.0	4	49.1	4	12.3	4	19.7	4	10.7	24.2	5	112.4
Elfry	2800	2287	4	31.9	4	46.4	4	13.2	4	18.2				4	109.5
Colsess	2792		4	26.5	4	38.1	4	10.8	4	10.7				4	85.9
Trebi	936	307	4	21.9	4	36.8	4	8.6	4	10.6	4	5.2	16.6	5	77.3
Arequipa	1256		4	35.4	4	44.4	4	15.3	4	15.8	4	9.6	24.1	5	112.1
Himalaya	620		2	28.9	4	34.2	4	8.1	4	14.6	4	2.8	17.7	5	82.4
Faust	4579	1084	2	16.8	4	33.2	4	6.5	4	10.6	4	2.9	14.0	5	65.1
Glabron	4577				4	44.1	4	6.4	4	13.8	4	3.0		4	85.5
Comfort	4578	336			4	47.8	4	13.0	4	15.9	4	8.1		4	107.8
Malt (local)	5677						4	11.3	4	14.2	4	9.3		3	91.6
Pearl (local)	5678								2	16.4	4	7.2		2	91.1
Blackhull selection	5679	1178									4	13.3		1	182.1
Pryor	2359										4	10.0		1	137.0
Vaughn	1367										4	12.3		1	168.5
Horn	926										4	4.9		1	67.1

[1] Standard variety with which others are compared.
[2] No yields reported for 1929 at Fort Lewis, as hail destroyed the crop.
[3] Yields for 1928 at Akron were corrected to take care of fractional plots. This was necessary because of faulty seeding of the drill.

GEORGIA

R. R. CHILDS, *professor of agronomy, Georgia State College of Agriculture, Athens;* J. L. STEPHENS, *forage-crop specialist, Georgia Coastal Plain Experiment Station, Tifton;* and R. P. BLEDSOE, *agronomist, Georgia Experiment Station, Experiment*

The yields from Georgia reported in table 5 are from plot tests at Athens and Tifton and from nursery tests at Experiment. Zero yields were due to winter-killing.

TABLE 5.—*Acre yields of varieties of barley grown at the Georgia State College of Agriculture, Athens; at the Georgia Coastal Plain Experiment Station, Tifton; and at the Georgia Experiment Station, Experiment, Ga., in 1 or more of the years 1927–31*

Data for Athens obtained in cooperation with the Georgia State College of Agriculture; data for Tifton obtained through the courtesy of the Georgia Coastal Plain Experiment Station; and data for Experiment obtained through the courtesy of the Georgia Experiment Station]

Station and variety	C.I. no.	Georgia no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Athens:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Greece [1]	4593		2	28.1	2	33.8	2	77.3	2	60.6	2	60.1	52.0	5	100.0
Argentine	4594		2	27.4	2	33.6	2	75.2	2	52.1	2	56.0	48.9	5	94.0
Tennessee Winter	257		2	29.0	2	33.2	2	55.5	2	54.1	2	57.4	45.8	5	88.2
Mammoth	4683		2	28.5	2	34.4	2	59.8	2	50.4	2	55.8	45.8	5	88.1
Tennessee Winter Selection 66	3546		2	21.1	2	25.2	2	55.0	2	49.4	2	53.0	40.7	5	78.4
Orel	4592		2	22.1	2	22.9	2	58.8	2	53.1	2	43.7	40.1	5	77.2
Nakano Wase	2164		2	26.0	2	25.9	2	49.0	2	56.9	2	35.7	39.3	5	75.6
Beardless 5	3384		2	14.3	2	13.1	2	25.4	2	46.7	2	27.3	25.4	5	48.8
Beardless 6	2746		2	17.5	2	20.2	2	27.6						3	46.9
Hannchen	531		2	25.4	2	5.9								2	50.6
South Carolina Awnless	5922								2	35.5	2	44.6		2	66.4
Tifton:															
Greece	4593				2	12.1	2	8.8	2	20.8	2	21.4	15.8	4	79.0
Tennessee Winter Selection 66 [1]	3546				2	8.7	2	15.4	2	20.3	2	35.5	20.0	4	100.0
Argentine	4594				2	10.8	2	8.6	2	16.9	2	19.0	13.8	4	69.2
Mammoth	4683				2	10.4	2	7.6	2	14.1	2	12.9	11.3	4	56.3
Tennessee Winter	257				2	8.4	2	11.8	2	12.0	2	16.7	12.2	4	61.2
Orel	4592				2	4.6	2	6.3	2	8.4	2	12.8	8.0	4	40.2
Hannchen	531				2	2.8	2	4.0	2	8.1				3	33.6
Beardless 5	3384				2	3.1	2	7.0	2	7.8	2	19.0	9.2	4	46.2
Beardless 6	2746				2	3.2	2	6.5	2	5.4				3	34.0
Nakano Wase	2164				2	10.2	2	6.0			2	32.3		3	81.4
South Carolina Awnless	5922										2	25.7		1	72.4
Experiment: [2]															
Chevalier		274		48.6		.0		35.0						3	80.5
Nakano Wase		170		43.7		(3)		53.4		.0		35.6		4	90.5
Greece		168		41.3		29.1		56.7		33.1		47.8	41.6	5	124.5
Tennessee Winter		169		37.0		19.3		56.8		31.9				4	110.3
Oderbrucker		275		36.7		.0		33.1						3	67.2
Wisconsin Winter [1]		172		29.5		20.5		53.9		27.6		35.6	33.4	5	100.0
Texas Winter		171		24.2		[4]16.8		58.4		28.2		34.1	32.3	5	98.8
Tennessee Winter Hooded		184		40.2		30.8		44.2		30.1		48.9	38.8	5	116.2

[1] Standard variety with which others are compared.
[2] The tests from Experiment are nursery tests. The varieties were grown in 4 series of 3 rod rows each.
[3] Destroyed by birds.
[4] Some grain lost in threshing, so not included in average.

The most promising variety tested in Georgia appears to be Greece (C.I. 4593). This is indicated not only in table 5, where it is shown to have given the highest yields at Athens and Experiment and good yields at Tifton, but also in summaries of previous years where this variety has shown to advantage. Tennessee Winter Selection 66 (C.I. 3546) produced the highest average yield at Tifton. At this place 2 out of the 4 years were good barley years, this being a greater percentage than average. Hooded winter varieties have produced satisfactory yields only at Experiment.

Barley seeding should be completed by early October in the northwestern part of the State and by October 25 elsewhere. The rate of 6 to 8 pecks of seed per acre is a satisfactory one.

IDAHO

UNIVERSITY OF IDAHO, MOSCOW

H. W. HULBERT, *head, Department of Agronomy*

Four distinct sets of conditions are represented in the localities from which yields are reported in table 6.

The southern Idaho irrigated area is represented by Aberdeen. Here Trebi is the outstanding variety, as it has been for many years. Moscow represents the Palouse section of Idaho. In this 5-year period, as in the previous one, Trebi is the highest-yielding variety of the spring-sown group. Winter Club produced the highest yield among the winter varieties. Felt is on the high bench lands of northeastern Idaho. During this 5-year period Meloy has exceeded Trebi in yield. In the previous 5 years the reverse was true. The 10-year average is somewhat in favor of Trebi, but the differences are such as to make little choice between them. Sandpoint is in the wooded northern section of the State. The Sandpoint results are not in close accord with those previously reported. Of the varieties grown in all 5 years, Han River and Horsford produced the highest yields. Hannchen (C.I. 531), grown for only 3 years, was very promising.

In the irrigated sections a seeding rate of 100 pounds of barley per acre is recommended. In the nonirrigated sections 6 pecks, decreasing to 4 or 5 pecks in the drier portions, is a sufficient quantity. Trebi barley is recommended for growing throughout Idaho. Charlottetown 80 is being distributed in cut-over areas, and it is believed that Hannchen would also be satisfactory in these areas.

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TABLE 6.—*Acre yields of varieties of barley grown at the Idaho Agricultural Experiment Station, Moscow, and at the substations at Aberdeen, Felt, and Sandpoint, Idaho, in 1 or more of the years 1927–31*

[Data for Moscow, Felt, and Sandpoint obtained through the courtesy of the Idaho Agricultural Experiment Station; data for Aberdeen obtained in cooperation with the Idaho Agricultural Experiment Station]

Station and variety	C.I. no.	Idaho no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Moscow:															
Spring-sown:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Trebi [1]	936	2073	2	52.0	2	82.1	5	36.7	5	52.2	3	78.5	60.3	5	100.0
Peruvian	935	2075	2	50.5	2	71.4	5	31.8	5	54.0	3	62.8	54.1	5	89.7
Han River	206	2072	2	46.7	2	71.0	5	38.8	5	48.3	3	67.3	54.4	5	90.2
White Smyrna	910	2074	2	45.5	2	67.7	5	53.9	5	68.0	3	60.9	59.2	5	98.1
Winter Club	488	2001	2	45.1	2	69.9	5	25.6	5	30.7	3	58.1	45.9	5	76.1
Baker	975	2076	2	44.3					5	45.0	3	63.1		3	83.4
Colsess	2792	2088	2	38.0	2	57.5	5	24.6	5	47.6	3	56.6	44.9	5	74.4
Faust	4579	2105	2	33.0	2	36.5	5	35.0	5	41.5	3	45.1	38.2	5	63.4
Ezond	5064	2112					5	39.0	5	51.2	3	74.8		3	98.6
Ace	1853	2109					5	41.0	5	51.7	3	68.9		3	96.5
Ottawa No. 7	5977	2107					5	45.1	5	44.9	3	61.6		3	90.6
Spartan	5027	2106					5	36.6	5	53.3	3	58.9		3	88.8
Union Beardless	5976	2108					5	33.2	5	52.2	3	48.5		3	79.9
Glabron	4577	2110					5	22.6	5	46.6	3	56.0		3	74.7
Velvet	4252	2111					5	24.7	5	36.7	3	47.1		3	64.8
Hannchen (229)	4841	2113							5	44.4	3	61.9		2	81.3
Baker	975	2114									3	65.7		1	83.6
Charlottetown 80	2732	2118									3	51.2		1	65.2
Fall-sown:															
Winter Club	488	2001	2	131.8	2	62.8	2	43.2	2	71.4	3	78.4	77.5	5	100.0
Do	519	2039	2	69.0	2	62.2	2	34.9	2	62.3				4	73.9
Tennessee Winter	257	2040	2	94.8	2	70.8	2	33.1	2	60.6				4	83.9
Michigan Winter	2036	2041	2	91.0	2	68.7	2	41.4	2	61.8				4	85.0
Sandpoint	5019	549									3	84.0		1	107.1
Aberdeen:															
Trebi [1]	936		1	95.4	2	80.0	2	93.4	3	130.3	3	85.2	96.9	5	100.0
Beldi Giant	2777		1	90.0	2	87.9	2	75.3	3	121.4	3	64.0	87.7	5	90.6
Hannchen	531		1	73.3	2	93.4	2	84.0	3	103.6	3	67.9	84.4	5	87.2
Bohemian	27		1	70.8										1	74.2
White Smyrna	910		1	84.2	2	87.5	2	82.1	3	117.9	3	83.2	91.0	5	93.9
Do	4580		1	81.3	2	92.5	2	80.4	3	117.3	3	77.1	89.7	5	92.6
Meloy	1176		1	65.4	2	84.6	2	79.8	3	93.6	3	59.8	76.6	5	79.1
Alpha	959		1	74.2	2	73.4	2	69.0						3	80.6
Flynn	1311		1	91.7	2	82.9	2	81.3	3	121.4	2	78.5	91.2	5	94.1
Orel	351		1	76.7	2	64.6	2	66.5						3	77.3
Horn	926		1	85.0	2	71.3	2	81.9	3	101.4	3	67.9	81.5	5	84.1
Faust	4579		1 [2]	47.9	2	66.7	2	66.9	3	76.9	3	41.6		4	64.8
Mechanical Mixture	4115		1 [3]	85.2	1	78.3		83.2	1	102.5				3	86.9
Composite Cross	4116		1 [3]	83.2	1	70.0		77.4	1	97.5				3	80.6
Bonami	4064		1 [3]	60.7	1	85.8								1	107.2
Ezond	5064				2	86.7	2	93.1	3	124.6	3	79.3		4	98.7
Arequipa	1256				1	115.0	2	80.4	3	113.1	3	72.9		4	98.1
Felt:															
Trebi [1]	936		2	15.8	2	55.8	2	25.0	2	20.8	2	14.5	26.4	5	100.0
Baker	975		2	14.1	2	55.8	2	25.0	2	24.1	2	10.0	25.8	5	97.8
Beldi Giant	2777		2	15.0	2	51.2	2	21.6	2	23.3	2	13.7	25.0	5	94.6
Han River	206		2	11.6	2	49.5	2	20.4	2	15.4	2	10.8	21.5	5	81.7
Meloy	1176		2	18.3	2	55.8	2	29.5	2	23.7	2	19.1	29.3	5	111.0
White Smyrna	910		2	10.0	2	43.7	2	20.8	2	21.2	2	13.7	21.9	5	82.9
Faust	4579		2	8.0	2	35.3	2	18.0	2	13.3	2	6.3	16.2	5	61.3
Nepal (White Hulless)	595		2	7.7	2	29.0	2	16.0	2	14.0	2	5.0	14.3	5	54.4

[1] Standard variety with which others are compared.
[2] Half of the 1/40-acre plot was damaged by sheep, and therefore yield is not included in average.
[3] These yields are not included in averages as they are from tests on 1/94-acre instead of 1/40-acre plots.

TABLE 6.—*Acre yields of varieties of barley grown at the Idaho Agricultural Experiment Station, Moscow, and at the substations at Aberdeen, Felt, and Sandpoint, Idaho, in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	Idaho no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Sandpoint:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Trebi[1]	936	-----	2	15.9	2	22.2	2	19.6	2	24.6	2	30.1	22.5	5	100.0
Han River	206	-----	2	22.6	2	29.6	2	20.7	2	23.7	2	28.8	25.1	5	111.6
Horsford	4665	-----	2	19.0	2	20.5	2	20.3	2	26.8	2	37.0	24.7	5	110.0
Winter Club	488	-----	2	15.1	2	26.1	2	15.0	2	25.0	2	33.6	23.0	5	102.1
Colsess	2792	-----	2	22.7	2	12.9	2	20.1	2	29.0	2	30.0	22.9	5	102.0
Nepal	595	-----	2	11.2	2	16.2	2	17.6	2	24.1	2	30.5	19.9	5	88.6
Faust	4579	-----	2	10.6	2	22.5	2	12.8	2	21.5	2	29.7	19.4	5	86.4
Charlottetown 80	2732	-----	2	19.3	2	30.6	2	21.9	2	22.8	2	25.8	24.1	5	107.1
Hannchen	531	-----	----	-----	----	-----	2	26.1	2	26.7	2	34.4	-----	3	117.4
Beldi Giant	2777	-----	----	-----	----	-----	2	20.3	2	23.8	2	38.3	-----	3	110.9
Flynn	1311	-----	----	-----	----	-----	2	19.0	2	18.9	----	-----	-----	2	85.7
Ezond	5064	-----	----	-----	----	-----	2	17.4	2	26.0	2	42.4	-----	3	115.5

[1] Standard variety with which others are compared.

ILLINOIS

AGRICULTURAL EXPERIMENT STATION, URBANA

W. L. BURLISON, *head, Department of Agronomy,* and G. H. DUNGAN, *associate professor, Crop Production*

Varietal tests of barley are again reported from Urbana and De Kalb. Varieties originating in Wisconsin appear to be well adapted to Illinois. Varieties of the Oderbrucker type produced the highest average yield in the years 1922–26. At present the Illinois Station is recommending Wisconsin Pedigree 37 and Wisconsin Pedigree 38 for general cultivation. As may be seen in table 7, these varieties have produced high yields since they have been included in the tests. Spartan and Lion are recommended where stiffness of straw is essential.

Barley is usually seeded at the rate of 8 pecks per acre in Illinois. Early seeding is very important on the southern edge of the barley belt. Around Urbana barley should be in the ground in late February or early March. The latter half of March is the best time to seed in sections represented by De Kalb.

TABLE 7.—*Acre yields of varieties of barley grown at the Illinois Agricultural Experiment Station, Urbana, and at the Crop Experiment Field, De Kalb, Ill., in 1 or more years 1927–31*

[Data obtained through the courtesy of the Illinois Agricultural Experiment Station]

Station and variety	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Urbana:														
Lion [1]	923	2	49.4	2	40.3	2	41.6	2	50.7	2	63.4	49.1	5	100.0
Silver King	890	2	49.8	2	45.6	2	30.7	2	45.2	---	---	---	4	94.1
Velvet	4252	2	49.1	2	42.6	2	33.5	2	42.6	2	56.3	44.8	5	91.3
Wisconsin Pedigree 5	1272	2	51.1	2	42.9	2	31.2	2	46.3	2	49.3	44.2	5	90.0
Wisconsin Pedigree 37	5028	---	---	2	49.1	2	48.8	2	53.2	2	62.9	---	4	109.2
Spartan	5027	---	---	2	46.9	2	41.5	2	51.0	2	68.3	---	4	106.0
Glabron	4577	---	---	---	---	2	37.4	2	49.9	2	53.5	---	3	90.4
Wisconsin Pedigree 38	5105	---	---	---	---	---	---	2	50.8	2	66.8	---	2	103.1
Trebi	936	---	---	---	---	---	---	---	---	2	72.4	---	1	114.2
De Kalb:														
Lion [1]	923	2	44.9	2	31.6	2	47.8	2	56.5	2	45.9	45.3	5	100.0
Velvet	4252	2	33.9	2	47.8	2	50.5	2	47.4	2	42.8	44.5	5	98.1
Silver King	890	2	29.0	2	49.3	2	52.2	2	47.5	---	---	---	4	98.5
Wisconsin Pedigree 5	1272	2	26.9	2	47.3	2	41.9	2	48.2	2	36.5	40.2	5	88.6
Wisconsin Pedigree 37	5028	---	---	---	---	2	60.6	2	55.5	2	42.2	---	3	105.4
Spartan	5027	---	---	---	---	2	48.7	2	49.5	2	47.7	---	3	97.1
Glabron	4577	---	---	---	---	2	47.9	2	52.3	2	45.6	---	3	97.1
Wisconsin Pedigree 38	5105	---	---	---	---	---	---	2	55.7	2	52.8	---	2	106.0
Trebi	936	---	---	---	---	---	---	---	---	2	44.3	---	1	96.5

[1] Standard variety with which others are compared.

INDIANA

AGRICULTURAL EXPERIMENT STATION, PURDUE UNIVERSITY, LA FAYETTE

R. R. MULVEY, *associate in crops, Department of Agronomy*

The climate of Indiana, as a whole, is not favorable to the profitable production of barley as compared with other small-grain crops. A limited number of both spring- and winter-barley varieties are maintained in comparative tests at La Fayette (table 8).

Over a period of years at La Fayette winter barley and the better adapted varieties of spring barley are practically equal in yielding ability. The same yield in bushels per acre is to be expected from winter wheat. Spring oats rank above either spring or winter barley, both as a feed and as a cash crop.

In the northern two tiers of counties and in the northeast section spring barley is profitably grown, as compared with oats, on the fertile loam soils. Acid soils and light sandy soils in this section are less adapted to the profitable production of this crop than oats.

The six-rowed Manchuria type has been chiefly grown by Indiana farmers in the past. This type is being rapidly replaced by the smooth-awned varieties which appear to be as well adapted and less objectionable to handle. The principal smooth-awned varieties being seeded are Wisconsin Pedigree 38, Velvet, and Spartan.

TABLE 8.—*Acre yields of varieties of barley grown at the Purdue University Agricultural Experiment Station, La Fayette, Ind., in 1 or more of the years 1927–31* [1]

Variety	C. I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Winter barley:														
Tennessee Winter [2]	257	2	53.9	2	15.1	2	28.5	2	26.5	2	56.2	36.0	5	100.0
Purdue 21	4581	2	52.0	2	21.5	2	26.7	2	31.6	2	54.8	37.3	5	103.6
Purdue 1101	4582	4	51.0	4	23.5	4	25.8	4	28.1	4	57.2	37.1	5	103.0
Tennessee Beardless	------	---	------	2	5.1	1	22.5	2	15.8	2	36.1	------	4	62.9
Spring barley:														
Manchuria [2]	2330	2	32.9	2	36.1	2	32.7	2	29.8	2	26.3	31.6	5	100.0
Lion	923	2	29.1	2	29.8	2	29.5	2	24.6	2	30.4	28.7	5	90.9
Success Beardless	1808	8	23.6	8	24.2	8	27.3	10	27.8	10	21.5	24.9	5	78.8
Colsess	2792	2	26.0	2	27.5	2	26.9	2	26.5	2	25.8	26.5	5	84.1
Alpha	959	1	29.5	2	38.2	2	41.3	2	32.3	2	34.6	35.2	5	111.5
Trebi	936	1	36.0	2	35.2	2	38.7	2	33.3	2	29.8	34.6	5	109.6
Minsturdi	1556	1	31.9	2	32.5	2	30.9	2	28.4	2	30.5	30.8	5	97.7
Comfort	4578	1	35.3	2	27.4	2	34.2	2	33.3	2	30.6	32.2	5	101.9
Velvet	4252	1	28.1	2	30.7	2	31.4	2	31.1	2	31.4	30.5	5	96.8
Glabron	4577	1	26.1	2	33.0	2	29.3	2	34.1	2	30.8	30.7	5	97.1
Spartan	5027	---	------	---	------	2	37.4	2	26.4	2	28.2	------	3	103.6
Wisconsin Pedigree 38	5105	---	------	---	------	---	------	2	32.8	2	30.8	------	2	113.4
Wisconsin Pedigree 37	5028	---	------	---	------	---	------	---	------	2	30.7	------	1	116.7

[1] Testing conditions for 1927 were not fully satisfactory.
[2] Standard variety with which others are compared.

From the more recent tests at La Fayette, Alpha appears to be much better adapted than Manchuria. Besides having higher yielding ability, it grows taller and the grain is of a higher test weight. Trebi ranks second to Alpha in all of these respects except in length of straw. Wisconsin Pedigree 37 is promising among the smooth-awned types. Should these varieties continue to outyield the varieties now being grown, the area of profitable barley production will be somewhat expanded in this State.

Recommendations as to varieties can be made with greater assurance after further testing. Spring barley should be seeded as early as possible, at the rate of 2½ bushels per acre. The time varies for the different sections of the State. September is the most favored time for fall seeding.

IOWA

AGRICULTURAL EXPERIMENT STATION, AMES

L. C. BURNETT, *Farm Crops and Soils Section*

The annual yields from the various trials in Iowa are reported in table 9. It is clear from all experiments that Trebi is a high-yielding variety. Spartan has made a good showing among the newer varieties. Several smooth-awned six-rowed sorts have produced higher yields than Manchuria. Velvet is suggested for either feed or market, if a smooth-awned variety is desired. Most barley varieties respond favorably to early sowing. The losses, however, are relatively small until the sowing has been delayed beyond the

middle of April. After this date the losses increase rapidly the longer sowing is delayed. Two bushels per acre is a satisfactory rate of seeding.

TABLE 9.—*Acre yields of varieties of barley grown at the Iowa Agricultural Experiment Station, Ames, and at the experiment fields at Mason City and Kanawha, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Iowa Agricultural Experiment Station. The results reported are from nursery tests The actual number of rows grown, rather than the number of replications, is given]

Station and variety	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Ames:			*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Trebi [1]	936	---	------	3	54.5	9	50.9	12	64.7	12	39.4	52.4	4	100.0
Glabron	4577	---	------	3	35.0	9	42.2	12	46.1	12	51.8	43.8	4	83.6
Minsturdi	1556	---	------	3	46.8	9	38.7	12	54.6	12	40.6	45.2	4	86.3
Velvet	4252	---	------	3	57.2	9	33.0	12	52.0	12	45.7	47.0	4	89.7
Wisconsin Pedigree 37	5028	---	------	3	47.4	9	34.2	12	56.2	12	41.9	44.9	4	85.8
Colsess	2792	---	------	3	45.5	9	36.5	12	41.0	12	41.3	41.0	4	78.4
Manchuria	241	---	------	3	54.2	9	33.7	12	40.7	12	31.0	39.9	4	76.2
O A.C. 21	1470	---	------	3	50.7	9	32.7	12	36.7	12	30.4	37.6	4	71.8
Spartan	5027	---	------	---	------	9	33.2	12	63.2	12	46.6	------	3	92.3
Mason City:														
Trebi [1]	936	---	------	3	75.0	6	45.2	8	56.9	----	------	------	3	100.0
Glabron	4577	---	------	3	57.8	6	30.4	8	44.3	----	------	------	3	74.8
Minsturdi	1556	---	------	3	51.3	6	35.2	8	47.8	----	------	------	3	75.8
Velvet	4252	---	------	3	68.5	6	27.5	8	41.1	----	------	------	3	77.4
Wisconsin Pedigree 37	5028	---	------	3	57.7	6	37.9	8	54.2	----	------	------	3	84.6
Colsess	2792	---	------	3	53.9	6	37.6	8	41.5	----	------	------	3	75.1
Manchuria	241	---	------	3	51.7	6	27.8	8	42.0	----	------	------	3	68.6
O.A.C. 21	1470	---	------	3	53.4	6	25.9	8	46.5	----	------	------	3	71.0
Spartan	5027	---	------	--	------	6	25.8	8	55.7	----	------	------	2	79.8
Kanawha:														
Trebi [1]	936	---	------	---	------	---	------	---	------	8	38.8	------	---	------
Glabron	4577	---	------	--	------	---	------	---	------	8	38.7	------	---	------
Minsturdi	1556	---	------	---	------	---	------	---	------	8	28.4	------	---	------
Velvet	4252	---	------	---	------	---	------	---	------	8	38.9	------	---	------
Wisconsin Pedigree 37	5028	---	------	---	------	---	------	---	------	8	33.7	------	---	------
Colsess	2792	---	------	---	------	---	------	---	------	8	26.2	------	---	------
Manchuria	241	---	------	---	------	---	------	---	------	8	27.5	------	---	------
O.A.C. 21	1470	---	------	---	------	---	------	---	------	8	25.4	------	---	------
Spartan	5027	---	------	---	------	---	------	---	------	8	34.5	------	---	------

[1] Standard variety with which others are compared.

KANSAS

KANSAS STATE COLLEGE OF AGRICULTURE, MANHATTAN

H. H. LAUDE, *professor of agronomy*

Several types of barley produce satisfactory yields in Kansas. Flynn, Vaughn, Stavropol, Blackhull, Trebi, and White Smyrna represent different types. As may be seen in table 10, Flynn does well in all five of the testing fields. Vaughn, another smooth-awned variety, has been tested for a shorter time. It is unquestionably promising. Stavropol is an old standard type that has made its way with farmers for many years. Blackhull has proved itself to be a good variety at Akron, Colo., and it apparently fits in well at Colby, Kans. There is

always some interest in the so-called "malt" varieties. These varieties yield fairly well, but they must be handled promptly to avoid loss from shattering. Three of these, Wingfield Malt, Local Malt, and Franklin Malt, at Colby, are nearly identical in appearance.

Extensive cooperative tests with a limited number of varieties have given results similar to the station tests.

It is recommended that barley be seeded during the last half of March at the rate of 1½ to 1¾ bushels per acre.

TABLE 10.—*Acre yields of varieties of barley grown at the branch experiment stations at Hays, Colby, Garden City, and Tribune, Kans.; and at the Kansas Agricultural Experiment Station, Manhattan, in 1 or more of the years 1927–31*

[Data for Hays obtained in cooperation with the Kansas Agricultural Experiment Station; for Colby, through the courtesy of the station and the Division of Dry Land Agriculture; and for Garden City, Tribune, and Manhattan, through the courtesy of the station]

Station and variety	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Hays:														
Club Mariout [1]	261	2	19.0	3	42.5	3	50.0	3	28.8	3	23.8	32.8	5	100.0
Flynn	1311	2	21.9	3	47.5	3	49.0	3	30.6	3	24.1	34.6	5	105.5
White Smyrna	195	2	18.5	3	53.1	3	52.1	3	35.0	3	26.9	37.1	5	113.1
Blackhull	878	2	22.1	3	34.9	---	---	---	---	---	---	---	2	92.7
Coast	690	2	15.4	3	40.8	3	34.9	---	---	---	---	---	3	81.7
Beldi Dwarf	190	2	7.6	3	49.4	---	---	---	---	---	---	---	2	92.7
Stavropol	2103	2	10.4	3	39.6	1	22.9	---	---	---	---	---	3	65.4
Gatami	575	2	9.9	3	30.9	---	---	---	---	---	---	---	2	66.3
Cape-Coast No. 11	4595	2	9.9	3	32.3	---	---	---	---	---	---	---	2	68.6
Meloy	1176	2	13.3	3	30.5	---	---	---	---	---	---	---	2	71.2
Himalaya	620	2	10.5	3	22.2	---	---	---	---	---	---	---	2	53.2
Hannchen	531	2	13.3	3	34.0	---	---	---	---	---	---	---	2	76.9
Odessa	182	2	14.6	3	41.8	---	---	---	---	---	---	---	2	91.7
Stavropol (Aberdeen)	------	2	19.6	3	42.1	1	37.5	---	---	---	---	---	3	89.0
Stavropol H.C. 249	5913	2	25.8	3	54.0	3	47.2	3	28.8	3	13.7	33.9	5	103.3
Ellis	2107	---	------	3	53.1	1	30.7	3	29.5	3	18.9	------	4	91.1
Colby Local Six-Rowed	5919	---	------	3	54.3	3	42.9	3	31.9	3	21.8	------	4	104.0
Huntington	4110	---	------	3	44.6	3	46.9	3	27.8	3	17.4	------	4	94.2
Francis	4109	---	------	3	42.8	3	46.2	---	---	---	---	------	2	96.2
Preston	1348	---	------	3	50.0	3	48.4	1	26.0	3	20.3	------	4	99.7
Vaughn	1367	---	------	3	50.0	3	49.6	3	29.2	3	24.1	------	4	105.4
Hero	1286	---	------	3	50.0	---	---	---	---	---	---	------	1	117.6
Pryor	2359	---	------	3	37.1	3	53.1	3	27.4	3	24.8	------	4	98.1
Franklin Malt	5915	---	------	---	------	3	42.9	3	29.8	3	13.4	------	3	83.9
Lion (Kansas Cooperative 1702)	923	---	------	---	------	3	38.3	3	28.8	---	---	------	2	85.2
Trebi	936	---	------	---	------	---	------	3	31.2	3	25.7	------	2	108.2
New Composite Cross	5461	---	------	---	------	---	------	1	26.5	1	22.4	------	2	93.0
Flynn Selection 13	5916	---	------	---	------	---	------	1	23.9	1	34.4	------	2	110.8
Flynn Selection 1	5911	---	------	---	------	---	------	---	---	3	25.8	------	1	108.4
Colby:														
Colby Local Six-Rowed	5919	---	16.9	2	41.1	2	32.2	3	51.7	3	17.0	31.8	5	112.5
White Smyrna	195	---	3.8	2	30.1	2	32.2	3	57.7	---	---	------	4	90.3
Blackhull	878	---	1.7	2	35.8	2	35.0	3	71.2	---	---	------	4	111.8
Stavropol	2103	---	3.0	2	42.7	2	36.3	---	---	---	---	------	3	117.5
Club Mariout [1]	261	---	2.1	2	34.8	2	32.9	3	58.7	3	12.7	28.2	5	100.0
Flynn	1311	---	3.8	2	36.3	2	43.5	3	60.1	3	14.0	31.5	5	111.7
Local Malt	4643	---	5.9	2	34.9	2	33.8	3	59.4	---	---	------	4	104.3
Wingfield Malt	4644	---	6.7	2	44.9	2	32.5	---	---	---	---	------	3	120.5
Coast	690	---	9.4	2	44.2	2	43.7	3	42.7	3	10.8	30.2	5	106.8
Odessa	182	---	5.1	2	29.7	2	26.0	3	53.5	---	---	------	4	88.9
Trebi	936	---	10.6	2	40.6	2	25.5	3	53.8	3	16.3	29.4	5	104.0
Himalaya	620	---	11.1	2	44.1	2	27.4	3	63.2	---	---	------	4	113.5

[1] Standard variety with which others are compared.

TABLE 10.—*Acre yields of varieties of barley grown at the branch experiment stations at Hays, Colby, Garden City, and Tribune, Kans.; and at the Kansas Agricultural Experiment Station, Manhattan, in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Colby—Continued.														
Hannchen	531		10.0	2	39.6	2	24.1	3	57.0				4	101.7
Huntington	4110			1	47.5	2	44.1	3	67.1	3	19.0		4	127.7
Francis	4109			1	43.8	2	36.8	3	65.8	3	19.6		4	119.3
Preston	1348			1	43.1	2	31.3	3	68.1	3	14.3		4	112.7
Vaughn	1367			1	46.7	2	29.7	3	64.1	3	11.8		4	109.5
Hero	1286			1	37.1	2	28.6	3	58.0				3	97.9
Stavropol H.C. 249	5913			1	51.5	2	37.5	3	61.8	3	19.8		4	122.6
Forsythe	2442			1	44.2	2	36.8						2	119.6
Lion	923					2	30.7	3	59.0				2	97.9
Franklin Malt	5915					2	26.3	3	55.2	3	16.2		3	93.7
Pryor	2359							3	60.1				1	102.4
Garden City:														
Ellis	2107	1	8.8		(2)	1	48.8	1	36.3		(3)		3	88.3
Coast	1430	1	15.0			1	53.8	1	20.0				3	83.5
Club Mariout [1]	261	1	17.5			1	48.8	1	40.0				3	100.0
Odessa	182	1	11.7										1	66.9
Flynn	1311					1	56.9	1	34.7				2	103.2
Stavropol H. C. 249	5913					1	47.5	1	17.5				2	73.2
Tribune:														
Ellis	2107	2	1.1	4	18.6								2	143.8
Club Mariout [1]	261	2	.9	4	12.8	4	14.9	4	32.4	3	13.7	14.9	5	100.0
Coast	690	2	1.2	4	19.8	4	20.3	4	26.5				4	111.1
Flynn	1311	2	.9	4	18.4	4	22.3	4	31.0	3	16.5	17.8	5	119.3
Local (Stavropol type)	4645	2	1.7	4	15.8	4	23.8	4	39.0				4	131.6
Stavropol H. C. 249	5913					4	20.4	4	35.4	3	13.7		3	113.9
Comfort	4578					4	17.2	4	21.7				2	82.2
Trebi	936					4	27.2	4	31.4	3	10.0		3	112.5
Vaughn	1367					4	19.1	4	29.4	3	12.8		3	100.5
Lion	923					4	26.4	4	32.4				2	124.3
Huntington	4110									3	15.0		1	109.5
Franklin Malt	5915									3	15.9		1	116.1
Manhattan:														
Coast	690	2	28.3	2	13.2	3	16.0	3	44.0				2	98.4
Flynn [1]	1311					3	9.9	3	51.1	3	35.7		3	100.0
Stavropol H. C. 249	5913					3	9.2	3	32.9	3	28.7		3	73.2
Comfort	4578					3	15.7	3	33.1				2	80.0
Velvet	4252					3	15.4	3	25.4				2	66.9
Vaughn	1367							3	49.0	3	36.1		2	98.0
Trebi	936									3	33.2		1	93.0

[1] Standard variety with which others are compared.
[2] No yields are reported at Garden City in 1928, as the crop was destroyed by hail.
[3] The yields for 1931 at Garden City were good, but inaccuracies in threshing made the data of no value.

MICHIGAN

AGRICULTURAL EXPERIMENT STATION, EAST LANSING

E. E. DOWN, *associate professor and research associate in farm crops*, and J. W. THAYER, Jr., *research assistant in farm crops*

Two-rowed varieties are relatively much better at East Lansing than at most stations. Alpha produced the highest yield of the varieties reported in table 11. Michigan Two-Row, one of the Hanna group, has always been a consistently high yielder and ranked second for the 4-year period. Spartan, a two-rowed, stiff-strawed, early maturing, smooth-awned barley, gave a lower yield than most of the

other varieties used in these trials. However, under field conditions its yields have been satisfactory, fields of Spartan having won each State barley-yield contest since 1929. Its uniformity and high test weight have brought it favor with pearlers and some maltsters, with the result that it commanded a substantial premium over six-rowed barley on the cash-crop market in Michigan in 1931. The station officials consider these advantages sufficient to justify its recommendation to Michigan growers. In Michigan, barley should be seeded as soon as the ground can be properly prepared in the spring. The usual rate of seeding is 1½ to 2 bushels per acre.

TABLE 11.—*Acre yields of varieties of barley grown at the Michigan Agricultural Experiment Station, East Lansing, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Michigan Agricultural Experiment Station]

Variety	C.I. no.	Michigan no.	Number of plots and acre yield [1]									Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		Average yield, 1927–30		
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Michigan Two-Row (Heil Hanna No. 1)[2]	2782	124	21	51.7	21	35.8	42	16.7	42	57.9	40.5	4	100.0
Spartan	5027	68	5	44.0	5	30.4	10	13.8	10	41.1	32.3	4	79.8
Velvet	4252	95	5	41.6	5	38.3	10	16.1	10	49.3	36.3	4	89.6
Glabron	4577	99	5	52.1	5	37.4	10	17.9	10	52.0	39.9	4	98.3
Minnesota 450	4646	100	5	46.1	5	36.9	10	17.8	10	41.1	35.5	4	87.5
Oderbrucker (Wisconsin Pedigree 9)	1275	101	5	40.6	5	35.4	10	19.7	10	45.8	35.4	4	87.3
Lion (Michigan Black Barbless)	923	102	5	44.1	5	31.0	10	14.1	9	50.4	34.9	4	86.1
Colsess	2792	120	5	45.4	5	31.4	10	15.6	10	35.4	32.0	4	78.8
Alpha	959	121	5	49.5	5	39.1	10	22.2	10	58.4	42.3	4	104.4
Hull-less (Coeleste)	4681	122	5	34.9	5	29.0	10	15.0	10	47.4	31.6	4	77.9

[1] No yields were recorded for 1931, as the plots were destroyed by wind.
[2] Standard variety with which others are compared.

MINNESOTA

UNIVERSITY FARM, ST. PAUL

LEROY POWERS, *assistant plant geneticist, Division of Agronomy and Plant Genetics*

Yields from six testing fields are reported in table 12. These results do not differ greatly in their trend from those of the previous 5-year period. The smooth-awned hybrid varieties have continued to produce high yields and are now widely grown. Glabron and Velvet have been recommended to the farmers. Glabron is superior to Velvet in yield and in strength of straw. Smooth-Awn×Manchuria (Minn. No. 462; C.I. 5998), was clearly the best variety at Crookston and was very promising at the other stations. Wisconsin Pedigree 38 has been included in the test for only a single year. In that year it showed much promise. Trebi, over the full period, is undoubtedly the highest-yielding variety. It has been

recommended by the experiment station to be grown for feed, but not for market, because the maltsters discriminate against this variety, and that part of the crop not used on the farm does not bring as high a price as do the varieties preferred by maltsters.

The varieties recommended by the station for all sections are Improved Manchuria (C.I. 2330), Glabron, and Velvet for ordinary conditions. Trebi is recommended for the Red River Valley, Minsturdi for heavy soils where other varieties suffer from lodging, and Peatland (C.I. 5267) for peatland. For the cut-over district in northeastern and north-central Minnesota, Svansota, a two-rowed variety, is suggested.

Barley should be seeded as early as the ground can be prepared. This can usually be done by April 10 in some parts of the State, while in other sections it may not be possible before April 25. The recommended rate is 2 bushels per acre.

TABLE 12.—*Acre yields of varieties of barley grown at the Minnesota Agricultural Experiment Station, University Farm, St. Paul; at the Northeast Experiment Station, Duluth; at the Southeast Experiment Station, Waseca; at the North Central Experiment Station, Grand Rapids; at the West Central Experiment Station, Morris; and at the Northwest Experiment Station, Crookston, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Minnesota Agricultural Experiment Station]

Station and variety	C.I. no.	Minnesota no.	Number of plots and acre yield												Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931		Average yield, 1927–31			
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield			Years	Yield
St. Paul:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*			*Pct.*
Manchuria	2330	184	3	47.5	3	32.9	3	48.9	3	34.1	3	27.0	38.1		5	81.7
Glabron	4577	445	3	45.4	3	30.1	3	51.8	3	42.0	3	43.1	42.5		5	91.1
Svansota	1907	440	3	45.0	3	38.1	3	51.2	3	32.3	3	35.1	40.3		5	86.5
Velvet	4252	447	3	43.4	3	28.4	3	49.5	3	36.6	3	39.9	39.6		5	84.9
Trebi [1]	936	448	3	60.2	3	34.1	3	60.7	3	41.5	3	36.6	46.6		5	100.0
Manchuria×Smooth Awn	4667	457	3	45.2	3	31.8	3	54.0	3	41.7	3	43.3	43.2		5	92.7
Smooth Awn×Manchuria	5998	462	3	50.3	3	37.5	3	58.1	3	41.0	3	36.6	44.7		5	95.9
Peatland	5267	452	3	49.0	3	34.8	3	49.4	3	33.1	3	32.8	39.8		5	85.4
Colsess	2792	461	3	45.9	3	31.5	3	44.6	3	30.0	3	33.5	37.1		5	79.6
Heinrich's		465	3	49.4	3	39.3	3	53.9	3	33.4	3	28.9	41.0		5	87.9
Svanhals×Lion	5999	474	---	---	---	---	3	54.6	3	30.4	3	30.0	---		3	82.9
Do	6000	475	---	---	---	---	3	47.7	3	24.5	3	24.7	---		3	69.8
Minsturdi	1556	439	---	---	---	---	---	---	3	37.0	3	28.5	---		2	83.9
Composite Cross	4116	---	---	---	---	---	---	---	3	37.5	3	32.1	---		2	89.1
Mechanical Mixture	4115	---	---	---	---	---	---	---	3	34.8	3	35.2	---		2	89.6
Wisconsin Pedigree 38	5105	529	---	---	---	---	---	---	---	---	3	39.3	---		1	107.4
Jean's	---	---	---	---	---	---	---	---	---	---	3	26.8	---		1	73.2
Duluth:																
Manchuria	2330	184	3	51.8	3	36.3	3	33.2	3	26.4	3	29.0	35.3		5	87.6
Glabron	4577	445	3	56.0	3	37.0	3	25.8	3	31.7	3	29.7	36.0		5	89.3
Svansota	1907	440	3	41.9	3	22.5	3	21.1	3	32.8	3	25.7	28.8		5	71.4
Velvet	4252	447	3	60.0	3	38.0	3	29.7	3	27.9	3	26.3	36.4		5	90.2
Trebi [1]	936	448	3	65.1	3	41.3	3	30.5	3	30.9	3	33.9	40.3		5	100.0
Manchuria×Smooth Awn	4667	457	3	53.2	3	35.1	3	34.0	3	37.8	3	33.6	38.7		5	96.0
Smooth Awn×Manchuria	5998	462	3	62.9	3	39.6	3	23.9	3	32.9	3	28.1	37.5		5	92.9

[1] Standard variety with which others are compared.

TABLE 12.—*Acre yields of varieties of barley grown at the Minnesota Agricultural Experiment Station, University Farm, St. Paul; at the Northeast Experiment Station, Duluth; at the Southeast Experiment Station, Waseca; at the North Central Experiment Station, Grand Rapids; at the West Central Experiment Station, Morris; and at the Northwest Experiment Station, Crookston, in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	Minnesota no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Duluth—Continued.															
Peatland	5267	452	3	56.4	3	35.5	3	28.8	3	27.5	3	32.0	36.0	5	89.3
Colsess	2792	461	3	62.5	3	34.4	3	28.5	3	33.2	3	21.0	35.9	5	89.0
Svanhals×Lion	5999	474					3	24.3	3	34.4				2	95.6
Do	6000	475					3	24.7	3	39.3	3	33.1		3	101.9
Wisconsin Pedigree 38	5105	529									3	31.6		1	93.2
Waseca:															
Manchuria	2330	184	3	41.3	3	57.4	3	49.5	3	40.4	3	48.9	47.5	5	80.8
Glabron	4577	445	3	39.4	3	56.7	3	52.4	3	38.8	3	55.2	48.5	5	82.5
Svansota	1907	440	3	36.3	3	55.3	3	47.1	3	40.5	3	47.3	45.3	5	77.0
Velvet	4252	447	3	39.8	3	54.9	3	48.9	3	37.8	3	50.2	46.3	5	78.7
Trebi [1]	936	448	3	53.8	3	67.5	3	63.9	3	45.1	3	63.8	58.8	5	100.0
Manchuria×Smooth Awn	4667	457	3	42.9	3	58.8	3	50.3	3	39.1	3	58.1	49.8	5	84.7
Smooth Awn×Manchuria	5998	462	3	42.7	3	65.5	3	53.7	3	46.0	3	65.8	54.7	5	93.1
Peatland	5267	452	3	45.4	3	53.0	3	50.5	3	42.7	3	48.6	48.0	5	81.7
Colsess	2792	461	3	35.6	3	55.2	3	46.2	3	38.3	3	47.2	44.5	5	75.7
Heinrich's		465			3	58.9	3	39.9	3	41.3	3	41.4		4	75.5
Dryland	5673	466			3	48.1	3	38.1						2	65.6
Svanhals×Lion	5999	474					3	41.4	3	44.4	3	46.5		3	76.6
Do	6000	475					3	45.0	3	41.9	3	46.8		3	77.4
Minsturdi	1556	439									3	48.2		1	75.5
Wisconsin Pedigree 38	5105	529									3	58.8		1	92.2
Grand Rapids:															
Glabron	4577	445	3	30.4	3	28.6	3	28.3	3	31.3	3	29.1	29.5	5	93.2
Svansota	1907	440	3	32.1	3	39.7	3	34.0	3	32.4	3	29.7	33.6	5	105.9
Velvet	4252	447	3	20.1	3	34.8	3	23.7	3	37.8	3	23.0	27.9	5	87.9
Trebi [1]	936	448	3	17.2	3	39.2	3	29.8	3	42.5	3	29.8	31.7	5	100.0
Manchuria×Smooth Awn	4667	457	3	32.7	3	33.8	3	31.3	3	33.4	3	32.2	32.7	5	103.1
Peatland	5267	452	3	14.9	3	44.4	3	27.1	3	38.9	3	34.7	32.0	5	100.9
Colsess	2792	461	3	26.9	3	28.2	3	32.5	3	28.4	3	28.8	29.0	5	91.4
Manchuria	2330	184			3	33.5	3	26.4	3	31.8	3	33.0		4	88.3
Smooth Awn×Manchuria	5998	462			3	40.3	3	30.6	3	38.9	3	24.9		4	95.3
Svanhals×Lion	5999	474					3	29.4	3	37.4	3	21.3		3	86.3
Do	6000	475					3	30.9	3	40.6	3	19.7		3	89.3
Heinrich's		465									3	23.2		1	77.9
Wisconsin Pedigree 38	5105	529									3	34.5		1	115.8
Morris:															
Manchuria	2330	184	3	43.6	3	35.1	3	27.3	3	19.3	3	27.4	30.5	5	83.9
Glabron	4577	445	3	50.0	3	32.4	3	34.5	3	23.9	3	28.8	33.9	5	92.9
Svansota	1907	440	3	49.1	3	42.3	3	31.4	3	26.4	3	25.8	35.0	5	95.9
Velvet	4252	447	3	45.6	3	36.8	3	26.6	3	28.1	3	26.1	32.6	5	89.4
Trebi [1]	936	448	3	54.6	3	27.4	3	28.3	3	28.4	3	43.8	36.5	5	100.0
Manchuria×Smooth Awn	4667	457	3	52.3	3	41.8	3	29.9	3	21.9	3	28.7	34.9	5	95.7
Smooth Awn×Manchuria	5998	462	3	31.3	3	38.3	3	29.3	3	34.1	3	30.4	32.7	5	89.5
Peatland	5267	452	3	45.4	3	26.8	3	26.5	3	26.0	3	29.9	30.9	5	84.7
Colsess	2792	461	3	41.9	3	29.6	3	26.3	3	22.0	3	26.2	29.2	5	80.0
Dryland	5673	466			3	29.1								1	106.2
Svanhals×Lion	5999	474					3	32.4	3	27.5	3	19.4		3	78.9
Do	6000	475					3	30.8	3	35.9	3	22.6		3	88.9
Heinrich's		465									3	20.4		1	46.6
Wisconsin Pedigree 38	5105	529									3	29.5		1	67.4

[1] Standard variety with which others are compared.

TABLE 12.—*Acre yields of varieties of barley grown at the Minnesota Agricultural Experiment Station, University Farm, St. Paul; at the Northeast Experiment Station, Duluth; at the Southeast Experiment Station, Waseca; at the North Central Experiment Station, Grand Rapids; at the West Central Experiment Station, Morris; and at the Northwest Experiment Station, Crookston, in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	Minnesota no.	Number of plots and acre yield												Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931		Average yield, 1927–31			
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield			Years	Yield
Crookston:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*			*Pct.*
Manchuria	2330	184	3	26.0	---	(2)	3	32.1	3	34.0	3	39.9	33.0		4	88.4
Glabron	4577	445	3	27.6	---	------	3	33.5	3	35.7	3	38.1	33.7		4	90.4
Velvet	4252	447	3	32.8	---	------	3	29.1	3	36.7	3	41.3	35.0		4	93.7
Trebi [1]	936	448	3	36.8	---	------	3	33.1	3	32.5	3	46.9	37.3		4	100.0
Manchuria×Smooth Awn	4667	457	3	25.9	---	------	3	40.1	3	35.9	3	45.7	36.9		4	98.9
Smooth Awn×Manchuria	5998	462	3	31.9	---	------	3	48.5	3	35.2	3	48.6	41.1		4	110.0
Peatland	5267	452	3	39.8	---	------	3	33.7	3	29.0	3	41.6	36.0		4	96.5
Svansota	1907	440	3	34.2	---	------	3	39.5	3	38.6	3	40.5	38.2		4	102.3
Colsess	2792	461	3	28.1	---	------	3	31.5	3	27.9	3	36.5	31.0		4	83.1
Svanhals×Lion	5999	474	---	------	---	------	3	35.3	3	32.1	3	37.6	------		3	93.3
Do	6000	475	---	------	---	------	3	39.5	3	36.7	3	44.1	------		3	106.9
Heinrich's	------	465	---	------	---	------	---	------	---	------	3	33.3	------		1	71.0
Wisconsin Pedigree 38	5105	529	---	------	---	------	---	------	---	------	3	49.9	------		1	106.4

[1] Standard variety with which others are compared.
[2] No yields are reported at Crookston in 1928, because of a crop failure.

MISSOURI

AGRICULTURAL EXPERIMENT STATION, COLUMBIA

ROY T. KIRKPATRICK, *assistant professor, Department of Field Crops*

The yields reported from Missouri are from nursery sowings at Columbia and from plot tests elsewhere (table 13). In the plot tests over the State, Trebi was the leading variety. It also showed up well in the nursery tests at Columbia. Although its yield was low in 1931, it was the leading variety in 1930. Some of the smooth-awned sorts showed promise in the nursery. Trebi is recommended to growers and should be seeded in March at the rate of 2 bushels per acre.

TABLE 13.—*Acre yields of varieties of barley grown at the Missouri Agricultural Experiment Station, Columbia, and in the experiment fields at Grain Valley, Maryville, Elsberry, Shelbyville, and Stark City in 1 or more of the years 1929–31*

[Data obtained through the courtesy of the Missouri Agricultural Experiment Station]

Station and variety	C.I. no.	Mo. no.	Number of plots and acre yield						Number of years grown and yield in comparison with standard variety for comparable years	
			1929		1930		1931			
			Plots	Yield	Plots	Yield	Plots	Yield	Average yield, 1929–31	Years	Yield
Columbia: [1]				*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Percent*
Oderbrucker [2]	940	B150	5	12.8	5	35.1	5	20.4	22.8	3	100.0
Flynn	1311	B63	5	10.1	5	28.4				2	80.4
Michigan 04103	4649	B70	5	12.0	5	32.6	5	20.7	21.8	3	95.6
Black Hull-less	596	B81	5	4.8	5	23.2	5	11.1	13.0	3	57.2
Success Beardless	1808	B83	5	5.6	5	35.5	5	27.7	22.9	3	100.7
Champion	2683	B84	5	7.5	5	29.6	5	19.6	18.9	3	83.0
Manchuria		B86	5	6.5	5	29.1	5	19.3	18.3	3	80.4
Do	244	B89	5	7.7	5	33.1	5	20.9	20.6	3	90.3
Improved Manchuria	2330	B94	5	6.9	5	39.4	5	21.6	22.6	3	99.4
Minsturdi	1556	B96	5	7.7	5	39.3	5	24.8	23.9	3	105.1
Hero	1286	B97	5	9.0	5	35.2	5	26.4	23.5	3	103.4
Bonami	4664	B100	5	11.3	5	34.5	5	18.0	21.3	3	93.4
Velvet	4252	B112	5	4.4	5	28.6	5	11.0	14.7	3	64.4
Eagle	913	B147	5	6.0	5	36.9	5	26.7	23.2	3	101.9
Odessa	916	B148	5	8.7	5	34.6				2	90.4
Steigum	931	B149	5	3.6	5	36.1				2	82.9
Red River	973	B151	5	4.1	5	32.6	5	14.4	17.0	3	74.8
Odessa	974	B152	5	6.5	5	32.7	5	15.3	18.2	3	79.8
Limerick	1302	B155	5	15.0	5	43.0	5	17.6	25.2	3	110.7
Trebi	936	B98			5	46.1	5	15.7		2	111.4
Sandrel	937	B99			5	37.3	5	19.1		2	101.6
Club Mariout	261	B162			5	27.4	5	17.3		2	80.5
Minnesota	576	B164			5	23.2	5	15.4		2	69.5
Blue Ribbon	611	B166			5	35.8	5	15.7		2	92.8
Manchuria	643	B167			5	28.9	5	8.4		2	67.2
Ruble	870	B169			5	37.0	5	22.4		2	107.0
Lion	923	B174			5	36.4	5	15.4		2	93.3
Summit	929	B175			5	41.0	5	21.6		2	112.8
Oderbrucker	969	B177			5	31.0	5	12.5		2	78.4
Hodge	982	B178			5	39.5	5	17.0		2	101.8
Nekludowi	1000	B179			5	34.4	5	22.2		2	102.0
Brutus	1011	B180			5	27.7	5	11.7		2	71.0
Chinerme	1079	B181			5	21.3	5	16.4		2	67.9
Crocket	1094	B182			5	43.7	5	12.5		2	101.3
Manchuria	1178	B183			5	32.9	5	20.4		2	96.0
Arequipa	1256	B184			5	36.1	5	16.5		2	94.8
Catts	1283	B186			5	32.6	5	12.1		2	80.5
Hopper	1285	B187			5	31.9	5	15.8		2	85.9
Sirroche	1289	B189			5	26.8	5	23.8		2	91.2
Kipper	1291	B190			5	32.0	5	16.9		2	88.1
Heron	1299	B191			5	27.4	5	15.1		2	76.6
Theodore	1300	B192			5	28.1	5	17.6		2	82.3
Peruvian	935	B15					5	19.0		1	93.1
Hurst	1304	B193					5	13.0		1	63.7
Vitz	1306	B194					5	19.3			94.6
Louden	1308	B195					5	12.7		1	62.3
Himalayan	4838	B201					5	12.1		1	59.3
Spartan	5027	B202					5	17.2		1	84.3
Columbia:											
Oderbrucker [2]							4	31.3		1	100.0
Velvet	4252						4	36.0		1	115.0
Trebi	936						4	36.3		1	116.0
Grain Valley:											
Oderbrucker [2]					3	26.3	4	37.7		2	100.0
Velvet	4252				3	30.3	4	33.0		2	98.9
Trebi	936				3	44.9	4	37.3		2	128.4

[1] Yields from replicated nursery plots consisting of 3 rod rows each.
[2] Standard variety with which others are compared.

TABLE 13.—*Acre yields of varieties of barley grown at the Missouri Agricultural Experiment Station, Columbia, and in the experiment fields at Grain Valley, Maryville, Elsberry, Shelbyville, and Stark City in 1 or more of the years 1929–31*—Continued

Station and variety	C.I. no.	Mo. no.	Number of plots and acre yield						Average yield, 1929–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Maryville:				*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Percent*
Oderbrucker [2]					4	24.3	5	22.6		2	100.0
Velvet	4252				4	23.4	5	17.1		2	86.4
Trebi	936				4	37.9	5	26.5		2	137.3
Elsberry:											
Oderbrucker [2]							4	48.6		1	100.0
Velvet	4252						4	44.1		1	90.7
Trebi	936						4	53.8		1	110.7
Shelbyville:											
Oderbrucker [2]							4	24.9		1	100.0
Velvet	4252						4	17.7		1	71.1
Trebi	936						4	24.3		1	97.6
Stark City:											
Oderbrucker [2]							4	8.7		1	100.0
Velvet	4252						4	2.7		1	31.0
Trebi	936						4	6.1		1	70.1

[2] Standard variety with which others are compared.

MONTANA

AGRICULTURAL EXPERIMENT STATION, BOZEMAN

CLYDE MCKEE, *agronomist, Department of Agronomy*

The climate of Montana is favorable to the growth of barley, and many varieties produce satisfactory yields when the rainfall is sufficient. At Havre, for instance, 11 varieties yielded more than 90 percent of Horn, the standard variety. This means that a choice of varieties based on yield alone is more or less arbitrary. Under dryland conditions the consideration of test weight as an indication of general quality of the grain appears important, since two-rowed hulled barleys may exceed six-rowed hulled types by as much as 5 pounds per bushel on the average. All things considered, the State-wide performances of Trebi and Horn are in themselves recommendations for these varieties (table 14).

Seeding should be done as early as the season permits and, for dry land, preferably on clean summer fallow. A satisfactory rate on nonirrigated land is 5 to 6 pecks per acre and for irrigated land, 8 pecks per acre.

TABLE 14.—*Acre yields of varieties of barley grown at the Montana Agricultural Experiment Station, Bozeman; at the Judith Basin Branch Station, Moccasin; at the North Montana Branch Station, Havre; and at the Huntley Field Station (dry land) in 1 or more of the years 1927–31*

[Data for Bozeman and Havre obtained through the courtesy of the Montana Agricultural Experiment Station; for Moccasin, in cooperation with the station; and for Huntley, through the courtesy of the Division of Dry Land Agriculture]

Station and variety	C. I. no.	Montana no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Bozeman:															
Trebi [1]	936	1500	3	76.4	3	61.8	3	93.6	3	97.8	3	65.5	79.0	5	100.0
B×White Club B	4674	1566	3	58.3	3	56.5	3	100.0	3	93.9	3	74.7	76.7	5	97.0
Himalaya	620	1549	3	46.6	3	43.0	3	69.4	3	81.4	3	68.9	61.9	5	78.3
Faust	4579	1573	3	49.4	3	45.3	3	75.5	3	80.0	3	60.8	62.2	5	78.7
Horn	926	1539	3	48.6	3	62.3	3	86.4	3	94.2	3	91.1	76.5	5	96.8
Atlas	4118	------	---	------	---	------	---	------	3	106.9	3	95.0	------	2	123.6
Moccasin:															
White Smyrna	195	------	4	18.6	4	50.4	4	16.0	4	19.3	---	------	------	4	81.7
Hannchen	531	------	4	30.0	4	51.7	4	13.2	4	16.3	4	16.4	25.5	5	85.5
Svanhals	187	------	4	26.1	---	------	---	------	---	------	---	------	------	1	80.3
Horn [1]	926	------	4	32.5	4	58.2	4	17.0	4	19.9	4	21.6	29.8	5	100.0
Alpha	959	------	4	27.2	4	36.7	---	------	---	------	---	------	------	2	70.5
Hannchen Selection	5462	------	1	36.8	4	54.2	4	18.3	4	19.1	4	18.8	29.4	5	98.7
Coast	690	------	4	28.8	4	59.8	4	20.8	4	20.5	4	22.6	30.5	5	102.2
Club Mariout	261	------	4	22.7	---	------	---	------	---	------	---	------	------	1	69.8
Hurst	1304	------	4	24.1	4	58.2	4	19.3	4	19.4	---	------	------	4	94.8
Hero	1286	------	4	18.2	---	------	---	------	---	------	---	------	------	1	56.0
Manchuria	244	------	4	20.7	---	------	---	------	---	------	---	------	------	1	63.7
Arequipa	1256	------	4	22.3	4	56.5	4	19.4	4	18.1	4	19.9	27.2	5	91.3
Himalaya	620	------	4	20.4	4	47.4	4	13.5	4	16.1	4	16.1	22.7	5	76.1
Faust	4579	------	4	22.6	4	49.0	4	15.8	4	15.6	4	16.7	23.9	5	80.2
Meloy Selection 3	4656	------	4	22.4	4	56.2	4	23.6	4	19.1	4	22.7	28.8	5	96.5
Composite Cross	4116	------	4	20.7	4	54.8	4	16.5	4	15.0	4	16.1	24.6	5	82.5
Mechanical Mixture	4115	------	4	22.0	4	57.3	4	17.4	4	17.7	4	20.3	26.9	5	90.3
Trebi	936	------	---	------	4	66.7	4	18.8	4	19.4	4	20.2	------	4	107.2
New Composite Cross	5461	------	---	------	---	------	---	------	4	17.7	4	18.4	------	2	87.0
Havre:															
Beldi Giant	2777	------	3	65.6	2	69.8	2	31.3	3	23.6	3	10.1	40.1	5	97.7
Trebi	936	------	3	64.6	3	71.2	3	34.4	3	22.6	3	11.5	40.9	5	99.6
Hannchen	531	------	3	63.3	2	76.6	3	30.6	3	16.3	3	11.5	39.7	5	96.7
Horn [1]	926	------	3	62.3	3	77.1	3	35.8	3	18.8	3	11.1	41.0	5	100.0
Coast	690	------	3	60.2	2	73.4	2	38.5	3	22.6	3	6.3	40.2	5	98.0
Sandrel	937	------	3	60.0	2	63.0	2	38.0	---	------	---	------	------	3	91.9
Meloy	1176	------	3	59.6	2	63.5	3	42.4	3	25.7	3	7.3	39.7	5	96.8
Holland	952	------	3	58.5	2	69.3	2	32.3	---	------	---	------	------	3	91.4
Han River	206	------	3	57.3	---	------	---	------	---	------	---	------	------	1	92.0
Steigum	907	------	3	56.8	2	69.3	3	35.1	---	------	---	------	------	3	92.0
Alpha	959	------	3	53.3	2	63.5	3	29.2	2	15.6	2	7.3	33.8	5	82.4
White Smyrna	195	------	3	47.1	3	62.1	2	39.6	3	21.5	3	10.1	36.1	5	88.0
Flynn	1311	------	3	45.0	2	62.0	2	42.7	2	24.5	2	7.8	36.4	5	88.7
Nepal	595	------	3	49.0	2	55.8	2	27.6	3	17.0	3	7.3	31.3	5	76.4
Faust	4579	------	3	48.6	2	61.0	3	26.8	3	17.8	3	5.6	32.0	5	77.9
Odessa	182	------	---	------	2	60.9	3	33.0	2	18.2	2	7.3	------	4	83.6
Spartan	5027	------	---	------	1	70.8	3	40.6	3	22.9	3	8.3	------	4	99.9
Velvet	4252	------	---	------	---	------	---	------	2	22.9	2	9.4	------	2	108.0
Huntley: [2]															
Trebi [1]	936	------	1	55.8	2	10.2	2	19.4	3	.0	---	.0	17.1	5	100.0
Himalaya	620	------	1	51.0	2	5.8	2	10.6	3	.0	---	.0	13.5	5	78.9
White Smyrna	195	------	1	50.4	2	6.6	2	16.9	3	.0	---	------	------	4	86.5
Horn	926	------	1	47.9	2	7.6	2	15.5	3	.0	---	.0	14.2	5	83.1
Hannchen	531	------	1	45.2	2	5.9	2	2.9	3	.0	---	.0	10.8	5	63.2
Success	------	------	---	------	---	------	2	7.9	3	.0	---	.0	------	3	40.7

[1] Standard variety with which others are compared.
[2] Crop failures in 1930 and 1931, due to drought.

NEBRASKA

AGRICULTURAL EXPERIMENT STATION, LINCOLN

T. A. KIESSELBACH, *professor of agronomy*, and W. E. LYNESS, *assistant in agronomy*

Trebi, Glabron, Comfort, and Short Comfort are recommended for growing in Nebraska. As can be seen in table 15, all four of these varieties produced high yields at Lincoln, while Trebi and Short Comfort were very good at North Platte. Trebi is especially popular under irrigation and for growing where the crop is harvested with a combine. In the previous 5 years White Smyrna (C.I. 658) and Smyrna (C.I. 2642) were among the better sorts. A number of varieties have been grown for only 1 or 2 seasons. Some of these are very promising but cannot safely be recommended until their test has extended over a longer period.

Barley is usually seeded at the rate of 2 to 2½ bushels per acre in eastern Nebraska. The rate diminishes materially toward the west, under upland conditions.

TABLE 15.—*Acre yields of varieties of barley grown at the Nebraska Agricultural Experiment Station, Lincoln, and at the North Platte Substation in 1 or more of the years 1927–31*

[Data for Lincoln obtained through the courtesy of the Nebraska Agricultural Experiment Station, and those for North Platte in cooperation with the station]

Station and variety	C. I. no.	Number of plots and acre yield										Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931			
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Average yield, 1927–31	Years	Yield
Lincoln:			*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Short Comfort	5907	3	54.0	3	59.1	3	40.7						3	95.1
Six-Row Common	4640	3	42.7	3	51.4	3	34.1	5	40.5	6	24.9	38.7	5	76.8
Manchuria	2330	3	38.8	3	55.2	3	34.9	5	41.2	6	30.5	40.1	5	79.6
Do	2947	3	48.9	3	51.0	3	35.5	5	44.9				4	85.9
Odessa	182	3	52.4	3	58.2	3	42.0	5	45.4	6	37.8	47.2	5	93.5
Club Mariout	261	3	38.4	3	41.1	3	40.7	5	52.0				4	82.0
Coast	690	3	43.3	3	59.6	3	47.0	5	58.6	6	35.9	48.9	5	96.9
Trebi [1]	936	3	52.7	3	55.9	3	53.1	5	48.3	6	42.1	50.4	5	100.0
McClymont	2126	3	45.6	3	61.6	3	46.5	5	53.3				4	98.6
O.A.C. 21	1470	3	49.6	3	40.0	3	35.5						3	77.4
Vulgare×Smooth Awn	4646	3	51.3	3	52.8	3	42.7	5	61.7				4	99.3
Flynn	1311	3	48.5	3	48.4	3	38.1	5	64.0	6	44.4	48.7	5	96.5
Velvet	4252	3	47.3	3	57.1	3	31.8	5	28.9				4	78.6
Lion (Black Barbless)	923	3	49.3	3	55.9	3	45.2	5	45.2				4	93.1
Glabron	4577	3	54.9	3	62.2	3	39.3	5	51.5	6	42.9	50.2	5	99.5
Hull-less (awnless)		3	23.1	3	38.0	3	29.1	5	39.2				4	61.6
Beardless		3	33.5	3	41.7	3	26.8						3	63.1
Do		3	33.8	3	42.7	3	26.9						3	63.9
Collsess	2792	3	42.5	3	52.3	3	46.1	5	50.8	6	39.3	46.2	5	91.6
Comfort	4578			3	61.2	3	37.2	5	47.7	6	39.8		4	93.2
Bon Ami	4664			3	52.6	3	33.7	5	50.2	6	38.8		4	87.9
Spartan	5027			3	49.0	3	38.1	5	55.4	6	45.9		4	94.5
Wisconsin Pedigree 37	5028			3	57.1	3	49.4	5	51.8	6	44.4		4	101.7
North Platte No. 1	5266							5	56.0	6	45.3		2	112.1
Horn	926							5	48.1	6	37.9		2	95.1
Vaughn	1367							5	51.8	6	39.5		2	101.0
Ezond	5064							5	52.1	6	44.3		2	106.6

[1] Standard variety with which others are compared.

TABLE 15.—*Acre yields of varieties of barley grown at the Nebraska Agricultural Experiment Station, Lincoln, and at the North Platte Substation in 1 or more of the years 1927–31*—Continued

Station and variety	C. I. no.	Number of plots and acre yield										Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931			
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Average yield, 1927–31	Years	Yield
North Platte:			*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
McClymont	2126	4	39.1	4	43.1	4	37.1	4	38.3	4	18.1	35.1	5	96.2
Six-Row Common	4640	4	37.3	4	43.1	4	33.1	4	43.1	4	18.7	35.1	5	96.0
Sandrel	937	4	38.1	4	46.2	4	31.2	4	44.8	4	21.1	36.3	5	99.3
Manchuria	2330	4	32.1	4	35.6	4	28.9	---	---	---	---	------	3	80.2
Composite Cross	4116	4	35.9	4	44.2	4	31.7	---	---	---	---	------	3	92.8
Mechanical Mixture	4115	4	38.1	4	47.7	4	31.5	---	---	---	---	------	3	97.3
Coast	690	4	41.1	4	45.8	4	32.9	4	43.5	4	17.7	36.2	5	99.1
Smyrna	2642	4	45.4	4	36.1	4	31.0	---	---	---	---	------	3	93.4
Butler	4589	4	41.9	4	36.1	4	32.9	---	---	---	---	------	3	92.0
Trebi [1]	936	4	40.0	4	43.0	4	37.5	4	42.9	4	19.2	36.5	5	100.0
Cape-Coast Hybrid	4654	4	40.4	4	57.9	4	25.8	---	---	---	---	------	3	103.0
Club Mariout	932	4	34.6	4	51.5	4	32.1	4	39.2	4	16.9	34.9	5	95.5
Snyder	4588	4	37.5	4	48.6	4	33.5	4	39.4	---	---	------	4	97.3
Hannchen	531	4	30.2	4	32.1	---	---	---	---	---	---	------	2	75.1
Short Comfort	5907	4	39.0	4	54.6	4	34.1	4	41.8	4	21.5	38.2	5	104.6
Blackhull	878	4	34.4	4	23.9	---	---	---	---	---	---	------	2	70.2
Colsess	2792	4	35.4	4	41.7	4	27.3	---	---	---	---	------	3	86.6
Velvet	4252	4	29.6	4	42.7	4	26.5	---	---	---	---	------	3	82.0
Himalaya	620	4	30.0	4	31.3	4	24.6	---	---	---	---	------	3	71.3
Arequipa	1256	---	------	4	45.0	4	33.7	4	40.8	4	17.3	------	4	95.9
Glabron	4577	---	------	---	------	4	30.4	4	29.2	4	20.0	------	3	79.9
North Platte No. 5	5510	---	------	---	------	4	38.1	4	39.1	4	19.8	------	3	97.4
North Platte No. 1	5266	---	------	---	------	4	37.7	5	42.8	12	20.2	------	3	101.1
North Platte No. 3	5526	---	------	---	------	4	30.8	4	38.1	---	---	------	2	85.7
North Platte No. 4	5488	---	------	---	------	4	31.7	4	50.2	4	20.0	------	3	102.3
North Platte No. 2	5471	---	------	---	------	4	31.2	4	40.2	---	---	------	2	88.8
Vaughn	1367	---	------	---	------	---	------	4	39.6	4	14.4	------	2	87.0
Comfort	4578	---	------	---	------	---	------	---	------	4	18.8	------	1	97 9
Flynn	1311	---	------	---	------	---	------	---	------	4	18.1	------	1	94.3
Ezond	5064	---	------	---	------	---	------	---	------	4	23.1	------	1	120.3
Spartan	5027	---	------	---	------	---	------	---	------	4	19.8	------	1	103.1
Smyrna Selection 280 (N. P.[2] 18)	5466	---	------	---	------	---	------	---	------	1	21.7	------	1	113.0
Coast 690–25 (N. P.[2] 19)	5483	---	------	---	------	---	------	---	------	1	20.8	------	1	108.3

[1] Standard variety with which others are compared.
[2] N.P.=North Platte.

NEW JERSEY

AGRICULTURAL EXPERIMENT STATION, NEW BRUNSWICK

HOWARD B. SPRAGUE, *agronomist*

An analysis of table 16 shows that Trebi has been the highest yielding variety in New Jersey in all of the years grown. It has not, however, been recommended to the farmers because of its rough awns and its tendency to lodge. Alpha and Velvet have been recommended for growing in all sections of the State. Alpha has been grown longer than either Velvet or Trebi, and in 1924 and 1925 it produced the highest yield of the varieties then under test. Bonami, a smooth-awned sort, has been promising for the 3 years compared. Its stand in 1931 was very poor owing to weevil injury of the seed, therefore the yield for that year was not considered comparable.

The usual rate of seeding is 10 pecks per acre, but for late seeding 12 pecks is probably a better rate. The usual seeding time in the New Brunswick area is April 15. April 1 is a more desirable date in the southern part of the State. In the northern districts seeding usually is done after April 15.

TABLE 16.—*Acre yields of varieties of barley grown at the New Jersey Agricultural Experiment Station, New Brunswick, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the New Jersey Agricultural Experiment Station. The 10 plots from which yields were taken as a basis for this test were each 12 feet in length, 3 rows wide, with 7 inches between rows]

Variety	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Alpha [1]	959	10	61.8	10	34.1	10	30.6	10	37.5	10	48.1	42.4	5	100.0
Club Mariout	261	10	62.0	----	------	----	------	----	------	----	------	------	1	100.3
Manchuria	244	10	59.8	----	------	----	------	----	------	----	------	------	1	96.8
Featherston	1120	10	50.5	----	------	----	------	----	------	----	------	------	1	81.7
Trebi	936	----	------	10	42.0	10	34.0	10	51.2	10	65.2	------	4	128.0
Horn	926	----	------	10	37.2	10	26.0	10	43.9	----	------	------	3	104.8
Velvet	4252	----	------	10	37.9	10	28.1	10	40.4	10	48.5	------	4	103.1
Bonami	4664	----	------	10	39.0	10	31.8	10	38.5	----	------	------	3	106.9
Comfort	4578	----	------	10	35.7	10	26.4	10	40.2	10	48.7	------	4	100.5
Svansota	1907	----	------	10	31.2	10	21.7	10	41.8	----	------	------	3	92.7
Glabron	4577	----	------	10	34.3	10	22.5	10	34.6	10	46.3	------	4	91.6
Spartan	5027	----	------	----	------	----	------	----	------	10	45.2	------	1	94.0

[1] Standard variety with which others are compared.

NEW MEXICO

AGRICULTURAL EXPERIMENT STATION, STATE COLLEGE

J. C. OVERPECK, *professor of agronomy*

Higher yields have been secured at State College, N.Mex., from fall seeding than from spring. The winters are mild, and most varieties can be successfully seeded in the fall. As can be seen in table 17, the unnamed variety, C.I. 4673, has been consistently better than the other varieties grown at State College. At Capulin, White Smyrna has produced the highest yields. The best period for seeding fall-sown barleys at State College is from September 15 to October 15 and for spring-sown varieties from February 1 to 15. The best rate of seeding is 90 to 100 pounds per acre. At Capulin, barley is seeded late in May or early in June at the rate of about 1 bushel to the acre.

TABLE 17.—*Acre yields of varieties of barley grown at the New Mexico Agricultural Experiment Station, State College, and at the Capulin field in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the New Mexico Agricultural Experiment Station]

Station and variety	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
State College:														
Spring sown:			*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Hanna	2788	3	35.0	4	33.4	3	19.8	3	27.3	3	51.7	33.4	5	58.7
Colsess	2792	3	25.4	4	33.4	3	22.7	3	29.7	2	54.9	33.2	5	58.3
Unnamed	4672	2	24.9	4	30.9	3	34.8						3	60.2
Hull-less		3	18.5	4	16.6								2	35.5
Club Mariout	261									2	61.8		1	104.4
Wisconsin Pedigree 38	5105									2	53.9		1	91.0
Trebi	936									2	53.8		1	90.9
Horn	926									1	31.9		1	53.9
Fausc	4579									1	25.7		1	43.4
Fall sown:														
Unnamed	4672	3	65.8	3	50.5	3	40.5	4	73.0	3	58.7	57.7	5	101.3
Tennessee Winter [1]	257	3	58.4	3	40.5	3	51.7	4	75.0	3	59.2	57.0	5	100.0
Unnamed	4673	3	71.1	3	57.8	3	64.7	4	80.8	3	74.5	69.8	5	122.5
Capulin:														
Colsess	2792	2	33.7	3	8.7					2	16.0		3	98.6
Club Mariout [1]	261	2	37.8	3	11.1	2	11.5	2	10.6	2	10.3	16.3	5	100.0
Odessa	182			1	14.0	2	17.8	2	4.2	2	14.3		4	115.6
White Smyrna	195			1	10.0	2	11.8	2	14.0	2	23.9		4	137.2
Stavropol (Kansas local)	2103			1	11.3	2	13.5	2	9.4	2	21.4		4	127.8
Stavropol H.C. 249	5913			1	10.5	2	10.9	2	8.8				3	91.0
Flynn	1311			1	11.8	2	12.3	2	5.7				3	89.8

[1] Standard variety with which others are compared.

NEW YORK

NEW YORK AGRICULTURAL EXPERIMENT STATION, CORNELL UNIVERSITY, ITHACA

H. H. LOVE, *professor of plant breeding*, and W. T. CRAIG, *experimentalist in plant breeding*

The results from Ithaca, N.Y., reported in table 18 were obtained in nursery tests. The highest 5-year average yield was secured from an unnamed selection (State selection 106–181). Its yield was distinctly higher than that of any other variety. The yield of Alpha was exceeded slightly by many other sorts. Alpha and Featherston No. 7 are still considered useful varieties for the farmer to grow. They should be seeded in April at the rate of 2 bushels per acre.

TABLE 18.—*Acre yields of varieties of barley grown at the New York Agricultural Experiment Station at Cornell University, Ithaca, in 1 or more of the years 1927–31*

[Data obtained in cooperation with the New York Agricultural Experiment Station. The yields of ten 1-rod rows were taken as the basis of each test]

Variety	C.I. no.	Cornell no.	Number of plots and acre yield										Average yield, 1927-31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Percent*
Alpha [1]	959		10	53.0	10	48.8	10	14.8	10	35.6	10	48.7	40.2	5	100.0
Chevron	1111		10	47.0	10	47.9	10	19.2	10	46.1	10	47.9	41.6	5	103.6
Swiss Spring	5900		10	49.4	10	44.6	10	18.9	10	46.2	10	47.2	41.3	5	102.7
Michung	1160		10	50.4	10	49.9	10	20.3	10	50.6	10	45.2	43.3	5	107.7
Lion×Manchuria	1192		10	52.7	10	45.7	10	18.6	10	48.3	10	45.3	42.1	5	104.8
Wisconsin			10	55.2	10	47.5	10	19.3	10	46.5	10	43.8	42.5	5	105.7
Silver King		101–19	10	50.9	10	42.0	10	18.6	10	47.4	10	41.0	40.0	5	99.5
Oderbrucker (Wisconsin Pedigree 5)	1272		10	47.8	10	46.0	10	18.5	10	50.6	10	42.6	41.1	5	102.3
Unnamed		2a–23–103	10	59.5	10	45.8	10	21.4	10	46.4	10	41.5	42.9	5	106.8
Do		101–58	10	42.1	10	42.2	10	19.9	10	43.2	10	40.4	37.6	5	93.5
Manchuria Pedigree	1244		10	49.6	10	45.2	10	19.4	10	50.1	10	40.8	41.0	5	102.1
Manchuria	643		10	48.5	10	47.4	10	19.7	10	47.0	10	40.5	40.6	5	101.1
Oderbrucker		103–42	10	48.3	10	50.3	10	18.0	10	48.5	10	38.9	40.8	5	101.5
Featherston No. 7	1120		10	42.9	10	47.4	10	14.6	10	42.6	10	38.8	37.3	5	92.7
Wisconsin 511			10	54.8	10	41.2	10	19.6	10	44.3	10	37.8	39.5	5	98.4
Red River	973		10	48.7	10	33.9	10	17.7	10	42.4	10	34.4	35.4	5	88.2
Comfort (451)	4578		10	59.1	10	50.5	10	19.9	10	41.9	10	46.3	43.5	5	108.4
Unnamed		2a–23–13–275–240	10	52.2	10	46.8	10	14.9	10	42.2	10	46.6	40.5	5	100.9
Do		2a–23–13–275–241	10	53.2	10	44.3	10	15.3	10	40.1	10	45.0	39.6	5	98.5
Do		2a–251	10	54.9	10	46.4	10	14.9	10	47.9	10	43.4	41.5	5	103.3
Velvet (447)	4252		10	49.6	10	44.5	10	18.9	10	48.7	10	42.1	40.8	5	101.4
Unnamed		2a–147	10	53.5	10	48.0	10	16.3	10	48.0	10	43.1	41.8	5	104.0
Do		2a–1	10	55.6	10	47.7	10	16.8	10	51.8	10	41.2	42.6	5	106.1
Do		2a–254	10	58.3	10	41.9	10	13.8	10	43.1	10	42.6	39.9	5	99.4
Do		2a–3	10	59.0	10	47.2	10	15.6	10	47.1	10	41.4	42.1	5	104.7
Do		2a–135	10	57.3	10	36.7	10	11.9	10	48.1	10	41.5	39.1	5	97.3
Do		2a–145	10	52.2	10	46.7	10	16.1	10	44.4	10	41.8	40.2	5	100.1

Do		2a-373	10	56.2	10	39.4	10	11.6	10	45.4	10	41.7	38.9	5	96.7
Do		2a-433	10	60.7	10	44.9	10	13.6	10	45.4	10	40.4	41.0	5	102.0
Do		2a-23-383	10	54.3	10	44.5	10	17.2	10	42.5	10	41.7	40.0	5	99.7
Do		2a-376	10	54.3	10	39.6	10	12.2	10	47.0	10	40.5	38.7	5	96.4
Do		2a-252	10	51.3	10	42.5	10	13.6	10	47.9	10	39.9	39.0	5	97.2
Do		2a-401	10	54.6	10	42.5	10	12.4	10	42.5	10	39.5	38.3	5	95.3
Do		2a-22-465-1	10	61.2	10	44.8	10	13.0	10	42.4	10	38.3	39.9	5	99.4
Do		2a-265	10	55.3	10	42.2	10	14.4	10	43.8	10	38.6	38.9	5	96.7
Glabron (445)	4577		10	52.4	10	38.4	10	15.3	10	41.8	10	35.4	36.7	5	91.2
Unnamed		State Sel. 106-181	10	62.4	10	50.1	10	19.0	10	50.0	10	54.0	47.1	5	117.2
Do		State Sel. 104-37	10	52.8	10	52.6	10	20.4	10	47.1	10	49.1	44.4	5	110.5
Do		State Sel. 104-14	10	49.8	10	47.5	10	16.9	10	42.0	10	48.1	40.9	5	101.7
Canadian (two-rowed)			10	57.7	10	53.7	10	18.7	10	43.2	10	46.8	44.0	5	109.6
Goldfoil	928		10	60.8	10	40.4	10	13.4	10	42.1	10	46.2	40.6	5	101.0
Unnamed		2a-22-420-3			10	50.7	10	20.3	10	50.2	10	39.9		4	108.9
Do		2a-22-422-3			10	47.3	10	19.3	10	43.9	10	40.9		4	102.4
Do		2a-22-422-2			10	47.9	10	19.5	10	41.6	10	38.6		4	99.8
Do		2a-22-420-5			10	51.2	10	18.1	10	42.1	10	37.9		4	100.9
Do		2a-22-86-2			10	49.2	10	16.3	10	43.7	10	43.2		4	103.0
Do		2a-22-86-1			10	48.7	10	15.7	10	45.8	10	40.8		4	102.1
Do		2a-22-3			10	46.6	10	11.8	10	41.7	10	39.4		4	94.3
Do		2a-22-15-2			10	43.8	10	14.3	10	41.2	10	37.8		4	92.7
Do		202al-2			10	45.7	10	14.6	10	43.2	10	37.9		4	95.6
Do		2a-22-86-4			10	48.3	10	19.1	10	41.4	10	39.2		4	100.1
Do		2a-22-15-1			10	46.9	10	14.6	10	46.1	10	36.3		4	97.3
O.K. Beardless					10	39.3	10	11.6	10	31.7	10	31.2		4	76.9
Unnamed		204al-1			10	47.9	10	17.0	10	40.2	10	41.5		4	99.1
Spartan	5027				10	44.2	10	12.5	10	27.4	10	34.8		4	80.4
Unnamed		210al-26-21					10	11.6	10	35.5	10	40.4		3	88.3
Do		204al-26-288					10	13.4	10	37.4	10	41.7		3	93.3
Swiss Spring		Sel. 87							10	44.9	10	47.6		2	109.7
Do		Sel. 129							10	45.7	10	45.2		2	107.8
Do		Sel. 297							10	45.9	10	45.2		2	108.1
Do		Sel. 132							10	45.9	10	44.0		2	106.6
Do		Sel. 217							10	43.7	10	42.5		2	102.3
Victory	5077								10	46.5	10	39.8		2	102.4
Wisconsin Pedigree 38	5105								10	51.0	10	51.5		2	121.6
Unnamed		204al-27-243							10	37.3	10	44.4		2	96.9

[1]Standard variety with which others are compared.

NORTH CAROLINA

AGRICULTURAL EXPERIMENT STATION, STATE COLLEGE STATION, RALEIGH

G. M. GARREN, *cereal agronomist*

The acreage of barley is increasing in North Carolina. The farmers prefer the hooded varieties even though they may yield less than the bearded ones. Actual tests are limited, but it will be noted that in 1931 the yield of the bearded variety was 120 percent of that of the best hooded one (table 19).

Rowan and Tennessee Beardless 6 are recommended. They should be seeded in October at the rate of 2 bushels per acre.

TABLE 19.—*Acre yields of varieties of barley grown at Piedmont Branch Station, Statesville, N.C., in the years 1927–31*

[Data obtained through the courtesy of the North Carolina Agricultural Experiment Station]

Variety	C.I. no.	Number of plots and acre yield [1]								Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1930		1931			
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Average yield, 1927–31	Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Rowan (North Carolina) [2]	5672	1	60.0	1	35.3	1	26.2	1	41.2	40.7	4	100.0
Tennessee Beardless 6	2746	1	48.2	1	36.0	1	29.5	1	35.4	37.3	4	91.6
Tennessee Beardless 5	3384	1	38.2								1	63.7
North Carolina (B)						1	25.0	1	49.5		2	110.5
Harlan Composite Cross (mixture no. 1)								1	47.9		1	116.3
Harlan Composite Cross (mixture no. 2)								1	45.8		1	111.2

[1] No yields reported for 1929.
[2] Standard variety with which others are compared.

NORTH DAKOTA

AGRICULTURAL EXPERIMENT STATION, STATE COLLEGE STATION, FARGO

T. E. STOA, *assistant agronomist*

Trebi has been the outstanding barley in North Dakota during the 5 years 1927–31. It will be noted in table 20 that Dickinson is the only station of the seven reported where the yield of Trebi is exceeded by other varieties. The two-rowed varieties have always done well at Dickinson, and Steigum has been the highest-yielding variety at that place. Of the commonly grown smooth-awned varieties tested during the 5-year period under discussion, Glabron was good at Dickinson, Williston, and Mandan. Velvet was among the best at Langdon and Hettinger for the years tested. Two new smooth-awned strains, Wisconsin Pedigree 37 and Wisconsin Pedigree 38, which were recently introduced into the tests at Langdon, showed promise. Lion, a black smooth-awned variety, was second in rank of the varieties tested for the entire 5-year period at Dickinson and was among the best at Fargo. Strains of Manchuria produced satisfactory

yields at Fargo, Dickinson, and Mandan (Featherston, C.I. 1120). The zero yields at Williston in 1931 were caused by drought.

Trebi is recommended as a feed barley throughout most of North Dakota. Manchuria is perhaps the best market variety, although Velvet also is satisfactory to maltsters.

In eastern North Dakota, Manchuria should be seeded at the rate of 6 pecks per acre, but 5 pecks is sufficient farther west. For Trebi and other large-seeded varieties, the rate should be higher. The seed should be sown in late April or early May.

TABLE 20.—*Acre yields of varieties of barley grown at the North Dakota Agricultural Experiment Station, Fargo; at the Dickinson, Edgeley, Hettinger, Langdon, and Williston Substations; and at the Northern Great Plains Field Station, Mandan, in 1 or more of the years 1927–31*

[Data for Fargo, Edgeley, Hettinger, Langdon, and Williston obtained through the courtesy of the North Dakota Agricultural Experiment Station; for Dickinson, in cooperation with the station; and for Mandan, in cooperation with the Division of Dry Land Agriculture]

Station and variety	C.I. no.	Station no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Fargo:															
Manchuria [1]	244	871	3	37.1	3	40.2	3	46.1	3	59.4	3	16.9	39.9	5	100.0
Do	2947	2121	3	38.8	3	41.8	3	53.9	3	59.4	3	24.7	43.7	5	109.5
Lion	923		3	44.6	3	35.1	3	54.7	3	64.7	3	22.0	44.2	5	110.7
Manchuria	2330	{Minn. 184}	3	38.0										1	102.4
Minsturdi	1556		3	37.8										1	101.9
Trebi	936		3	44.4	3	46.8	3	54.6	3	66.7	3	25.6	47.6	5	119.2
Odessa	182		3	38.9	3	39.6	3	52.5	3	59.0	3	26.3	43.3	5	108.3
Velvet	4252		3	34.7	3	35.6	3	46.7	3	54.2	3	20.3	38.3	5	95.9
Mechanical Mixture	4115		3	37.1	3	37.9	3	47.8	3	56.5				4	98.1
Composite Cross	4116		3	37.5	3	39.1	3	50.7	3	58.4	3	20.4	41.2	5	103.2
O.A.C. 21	1470		3	41.2	3	40.2	3	47.5	3	58.1	3	23.3	42.1	5	105.3
Glabron	4577		3	34.9	3	34.6	3	41.5	3	53.5	3	20.4	37.0	5	92.6
Bearer	4707		3	36.7	3	42.6	3	47.2	3	50.8	3	13.8	38.2	5	95.7
Wing Pedigree	1177		3	32.9	3	32.6								2	84.7
Nepal	262		3	29.3	3	21.3	3	35.5	3	40.8	3	7.1	26.8	5	67.1
Hannchen	531		3	42.3	3	46.9	3	59.1	3	62.0	3	19.3	45.9	5	115.0
Duckbill	1916		3	25.3	3	29.9	3	41.0	3	44.1				4	76.8
Charlottetown 80	2732		3	31.3	3	36.7	3	42.0	3	50.6				4	87.9
Svansota	1907				3	42.4	3	51.8	3	53.8	3	16.4		4	101.1
Spartan	5027						3	41.7	3	52.2	3	20.8		3	93.7
Wisconsin Pedigree 38	5105								3	62.8	3	12.0		2	98.0
Steigum	907										3	23.0		1	136.1
Edgeley:															
Manchuria	2947		3	53.8	3	23.1	3	29.0	3	26.1	3	21.2	30.3	5	74.0
Trebi [1]	936		3	55.9	3	30.0	3	53.5	3	36.2	3	29.0	40.9	5	100.0
Nepal	262		3	33.7	3	13.3	3	32.9	3	27.6	3	12.4	24.0	5	58.6
Hannchen	531		3	56.9	3	25.3	3	40.8	3	29.4	3	18.3	34.1	5	83.4
Velvet	4252				3	33.9	3	30.3	3	30.6	3	20.4		4	77.5
Glabron	4577				3	29.2	3	35.0	3	28.8	3	20.7		4	76.5
Odessa	182				3	30.6	3	40.8	3	26.4	3	24.8		4	82.3
Svansota	1907				3	26.1	3	34.4	3	33.0	3	17.7		4	74.8
Bearer	4707						3	29.7	3	31.4	3	11.9		3	61.5
Spartan	5027						3	27.5	3	33.0	3	22.2		3	69.7
Wisconsin Pedigree 38	5105										3	20.9		1	72.1
Fredenburg											3	25.4		1	87.6
Steigum	907										3	20.9		1	72.1

[1] Standard variety with which others are compared.

TABLE 20.—*Acre yields of varieties of barley grown at the North Dakota Agricultural Experiment Station, Fargo; at the Dickinson, Edgeley, Hettinger, Langdon, and Williston substations; and at the Northern Great Plains Field Station, Mandan, in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	Station no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		Bu.		Bu.		Bu.		Bu.	Bu.		Pct.
Hettinger:															
Manchuria	2947		(2)	(2)	3	39.9	3	28.3	3	23.9	3	5.5	24.4	4	72.7
Trebi [1]	936				3	51.0	3	34.3	3	36.3	3	12.6	33.6	4	100.0
Nepal	262				3	27.9	3	21.5	3	32.1	3	4.7	21.6	4	64.2
Hannchen	531				3	39.9	3	31.9	3	19.2	3	9.1	25.0	4	74.6
Velvet	4252						3	29.8	3	31.9	3	6.5		3	82.0
Glabron	4577						3	24.6	3	31.9	3	5.0		3	73.9
Svansota	1907						3	31.2	3	27.0	3	5.2		3	76.2
Steigum	907								3	29.3	3	8.4		2	77.1
Wisconsin Pedigree 38	5105										3	7.2		1	57.1
Odessa	182										3	8.5		1	67.5
Dryland	5673										3	8.8		1	69.8
Langdon:															
Nepal	595		3	37.0	3	21.3	3	17.5	3	23.1	3	17.9	23.4	5	48.1
Manchuria	2947		3	52.2	3	35.8	3	19.9	3	44.1	3	23.5	35.1	5	72.3
Trebi [1]	936		3	79.1	3	43.8	3	30.5	8	60.4	3	28.8	48.5	5	100.0
Bearer	4707		3	65.4	3	39.1	3	14.5	3	45.3	3	22.6	37.4	5	77.0
Hannchen	531		3	74.5	3	42.0	3	24.1	3	54.4	3	26.6	44.3	5	91.3
Glabron	4577				3	32.5	3	20.5	3	43.5	3	24.6		4	74.1
Velvet	4252				3	33.3	3	21.5	3	47.1	3	26.5		4	78.5
Svansota	1907				3	29.1	3	20.8	3	56.9	3	26.6		4	81.6
Spartan	5027						3	23.8	3	37.9	3	15.9		3	64.8
Wisconsin Pedigree 37	5028								3	64.4	3	30.9		2	106.8
Wisconsin Pedigree 38	5105										3	33.4		1	116.0
Steigum	907										3	25.0		1	86.8
Williston:															
Manchuria	882	170	3	41.0	3	50.5	3	39.2	3	27.1				4	71.7
Do	2947		3	50.8	3	53.4	3	41.1	3	28.5	3	.0	34.8	5	79.0
Trebi [1]	936		3	53.9	3	69.3	3	52.7	3	44.2	3	.0	44.0	5	100.0
Nepal	262		3	37.5	3	30.4	3	34.4	3	22.9	3	.0	26.0	5	59.2
Hannchen	531		3	48.3	3	60.3	3	40.4	3	31.1	3	.0	36.0	5	81.8
Glabron	4577				3	46.8	3	49.8	3	36.4	3	.0		4	80.0
Velvet	4252				3	42.9	3	43.0	3	21.7	3	.0		4	64.7
Svansota	1907						3	37.4	3	30.8	3	.0		3	70.4
Steigum	907						3	49.1	3	28.2	3	.0		3	79.8
Wisconsin Pedigree 38	5105											.0		1	
Mandan:															
Featherston	1120		3	12.3	3	36.2	3	16.9	3	11.9	3	12.1	17.9	5	100.3
Odessa	182		3	20.5	3	38.5	3	22.9	3	11.6	3	12.8	21.3	5	119.3
Trebi	936		3	21.3	3	49.1	3	21.7	3	12.0	3	13.5	23.5	5	132.0
Meloy	1176		3	16.2	3	24.7								2	76.9
Alpha	959		3	18.2	3	39.3	3	16.2	3	6.1				4	106.1
Horn	926		3	24.6	3	44.3	3	19.6	3	3.2	3	13.2	21.0	5	117.7
Orel	351		3	26.8	3	27.1								2	101.3
Hannchen [1]	531		3	19.4	3	33.8	3	20.8	3	1.2	3	13.9	17.8	5	100.0
Charlottetown 80	2732				1	32.8	1	11.3						2	80.8
Glabron	4577						3	20.8	3	13.0	3	13.9		3	132.9
Vaughn	1367						3	16.7	3	7.5	3	6.1		3	84.4
New Composite Cross (spring)	5461								1	.5	2	13.3		2	91.4
Dickinson:															
White Smyrna	658		3	22.6	3	26.7	3	11.0	3	22.8	3	5.3	17.7	5	81.2
Steigum	907		3	31.2	3	38.2	3	21.2	3	31.1	3	5.4	25.4	5	116.7
Hannchen [1]	531		3	29.2	3	32.1	3	18.4	3	25.3	3	3.9	21.8	5	100.0
Hanna	203		3	27.2	3	31.5	3	17.9	3	28.2	3	3.1	21.6	5	99.1
Scholey	962		3	25.5	3	33.7	3	15.1	3	22.7				4	92.4

[1] Standard variety with which others are compared.
[2] No yields are reported for 1927 at Hettinger, as hail destroyed the crop.

TABLE 20.—*Acre yields of varieties of barley grown at the North Dakota Agricultural Experiment Station, Fargo; at the Dickinson, Edgeley, Hettinger, Langdon, and Williston Substations; and at the Northern Great Plains Field Station, Mandan, in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	Station no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Dickinson—Continued.				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Svanhals	187		3	22.8	3	28.4	3	12.8	3	19.3				4	79.3
Gold	1145		3	27.6	3	33.6	3	14.6	3	19.7				4	91.0
Charlottetown 80	2732		1	21.0	3	29.2	3	13.6	3	25.9				4	85.4
Duckbill	1916		1	20.0	3	25.7								2	74.6
Manchuria	244		3	29.3	3	26.5	3	15.0	3	33.5	3	6.1	22.1	5	101.4
Odessa	182		3	28.9	3	27.6	3	18.6	3	33.5	3	3.8	22.5	5	103.2
Lion	923		3	30.6	3	23.4	3	19.3	3	35.8	3	6.3	23.1	5	106.0
Flynn	1311		3	15.9										1	54.5
Club Mariout	932		3	16.6										1	56.8
White Gatami	920		3	20.4	3	19.4								2	64.9
Nepal	262		3	26.4	3	23.2	2	10.4	3	30.8	2	2.8	18.7	5	86.0
Wing Pedigree	1177		3	19.1	3	17.0								2	58.9
Velvet	4252				3	24.6	3	16.6	3	30.1	3	3.6		4	94.0
Glabron	4577				3	26.1	3	18.4	3	36.3	3	6.4		4	109.4
Svansota	1907						3	17.8	3	29.1	3	3.5		3	105.9
Horn	926						3	19.9	3	31.6	3	1.2		3	110.7
Trebi	936						3	9.6	3	26.5	3	5.3		3	87.0
Wisconsin Pedigree 38	5105										3	6.4		1	164.1
Regal	5030										3	6.2		1	159.0

OHIO

J. B. PARK, *chairman, Department of Farm Crops, Ohio State University, Columbus, and associate in agronomy, Ohio Agricultural Experiment Station, Wooster*

More than half of Ohio's total barley crop is grown in 10 of the northwestern counties. In northeastern Ohio the prevailingly acid soils are unfavorable to barley, and in the southern part the climate is unfavorable to spring barley. Winter barley is grown somewhat in four southwestern counties, but the total acreage is small.

The yield tests reported in table 21 show that Glabron is definitely superior to Velvet at all stations where tests were made, except at Columbus and in Hamilton County. At Columbus the two are practically equal. In Hamilton County spring barley is grown very little. Glabron and Velvet are recommended throughout the State. Trebi has made an excellent record at Columbus. It has not been recommended to growers as yet because of the prejudice against rough awns, and because it sometimes grows so short that harvesting is difficult.

The recommended rate of seeding is 2 bushels per acre. It should be sown the first week of April, or as soon after that as the soil is in condition for working.

TABLE 21.—*Acre yields of varieties of barley grown at the Ohio Agricultural Experiment Station, Wooster; at the Ohio State University, Columbus; and at 4 county experiment farms—Paulding (northwest), Miami and Madison (west central), and Hamilton (southwest)—in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Ohio Agricultural Experiment Station]

Station and variety	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Wooster:			*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Wisconsin Pedigree	835	2	39.5	---	------	---	------	---	------	---	------	------	1	80.9
Lion (Michigan Black Barbless)	923	2	44.6	2	31.4	2	10.9	2	15.4	2	51.2	30.7	5	97.6
Velvet	4252	2	55.8	2	42.1	2	15.4	2	20.9	2	54.4	37.7	5	120.0
Oderbrucker [1]	836	2	48.8	2	36.5	2	11.6	2	16.6	2	43.7	31.4	5	100.0
Featherston	1120	2	47.0	2	43.3	2	12.6	2	21.9	2	42.0	33.4	5	106.1
O.A.C. 21	1470	2	47.8	2	42.8	2	15.0	2	19.6	2	50.0	35.0	5	111.5
Trebi	936	2	63.2	2	34.5	2	12.5	2	15.3	2	42.7	33.6	5	107.0
Nepal (White Hull-less) [2]	595	2	24.8	2	17.0	2	6.0	2	20.0	2	33.6	20.3	5	64.5
Manchuria (Minnesota 184)	2330	2	51.5	2	41.2	2	12.1	2	19.7	2	42.3	33.4	5	106.1
Minsturdi	1556	2	51.0	2	20.1	2	13.0	2	16.9	2	56.1	31.4	5	99.9
Horn	926	2	62.5	2	36.8	2	13.5	2	24.4	2	45.2	36.5	5	116.0
Alpha	959	2	63.6	2	40.2	---	------	---	------	2	54.3	------	3	122.6
Glabron	4577	---	------	2	46.3	2	16.6	2	22.1	2	51.7	------	4	126.1
Spartan	5027	---	------	2	41.3	2	14.2	2	20.1	2	52.5	------	4	118.2
Wisconsin Pedigree 37	5028	---	------	2	47.9	2	14.7	2	17.7	2	51.5	------	4	121.6
Hooded (Horsford)	------	---	------	2	29.1	2	8.4	2	17.4	2	47.8	------	4	94.7
Columbus:														
Oderbrucker [1]	836	3	42.5	3	54.6	3	42.3	3	36.6	3	59.9	47.2	5	100.0
Featherston	1120	3	39.8	3	65.7	3	45.1	3	40.0	3	65.9	51.3	5	108.7
Velvet	4252	3	49.6	3	55.6	3	42.3	3	40.9	3	64.0	50.5	5	107.0
Six-Row Hooded	------	3	39.6	3	45.7	3	33.8	3	38.3	3	48.5	41.2	5	87.3
Trebi	936	3	50.4	3	72.0	3	47.2	3	46.9	3	75.7	58.4	5	123.9
Nepal (White Hull-less) [2]	595	3	22.8	3	26.7	3	23.9	3	16.2	3	40.7	26.1	5	55.2
Glabron	4577	---	------	---	------	3	40.4	3	45.2	3	61.5	------	3	106.0
Spartan	5027	---	------	---	------	3	35.9	3	40.0	3	59.9	------	3	97.8
Comfort	4578	---	------	---	------	---	------	---	------	3	60.7	------	1	101.3
Paulding County:														
Oderbrucker [1]	836	3	17.5	3	41.7	3	30.3	3	33.9	3	33.0	31.3	5	100.0
Velvet	4252	3	12.3	3	40.6	3	13.3	3	33.8	3	31.8	26.4	5	84.3
Glabron	4577	3	24.3	3	43.9	3	24.2	3	43.9	3	34.5	34.2	5	109.2
Trebi	936	---	------	3	50.2	3	36.9	3	34.4	3	27.6	------	4	107.3
Miami County:														
Oderbrucker [1]	836	3	42.4	3	23.7	3	23.3	3	48.3	3	29.4	33.4	5	100.0
Velvet	4252	3	33.2	3	16.4	3	30.2	3	47.6	3	34.4	32.4	5	96.8
Glabron	4577	---	------	---	------	3	28.1	3	48.4	3	31.6	------	3	107.0
Madison County:														
Oderbrucker [1]	836	3	31.7	3	33.3	3	40.2	3	33.8	3	36.9	35.2	5	100.0
Velvet	4252	3	35.0	3	35.6	3	35.4	3	29.5	3	44.0	35.9	5	102.0
Glabron	4577	---	------	---	------	3	40.2	3	30.7	3	42.0	------	3	101.8
Hamilton County:														
Oderbrucker [1]	836	3	38.1	3	27.9	3	7.5	3	8.5	3	15.2	19.4	5	100.0
Nepal (White Hull-less) [2]	595	3	28.7	3	8.0	---	------	---	------	---	------	------	2	55.6
Velvet	4252	---	------	3	34.0	3	32.5	3	6.3	3	18.3	------	4	154.1
Glabron	4577	---	------	---	------	3	12.8	3	7.1	3	16.5	------	3	116.7
Spartan	5027	---	------	---	------	3	5.6	3	12.9	3	21.0	------	3	126.6

[1] Standard variety with which others are compared.
[2] Yields were calculated to 15 percent of hull.

OKLAHOMA

OKLAHOMA AGRICULTURAL COLLEGE, STILLWATER

N. E. WINTERS, *head, Department of Agronomy*, and C. B. CROSS, *assistant cerealist, Department of Agronomy*

Yields from four stations in Oklahoma are reported in table 22. At Stillwater, Ardmore, and Carrier the results were obtained from nursery rows. At Lawton the varieties were tested in field plots.

As a whole, the experiments have been carried on too short a time to obtain significant results. Oklahoma is on the border line where both spring and winter types can be grown; the seasonal fluctuations must favor first one, then another. A longer period of testing is needed here than in most localities. In the tests so far some varieties of all types have done well. The winter varieties are apparently the most dependable. Varieties of the north-African group have done well only at Ardmore. Several of the smooth-awned hybrids are promising although, with the exception of Hero, they have been included for very brief periods. Hero and Vaughn have made the best showing to date.

Fall-sown barley should be in the ground by October 15. A desirable rate for fall seeding is 2 bushels per acre. Spring seeding should be done between February 10 and March 10. The rate of seeding increases from west to east. In western Oklahoma 5 pecks per acre is sufficient, while 8 pecks may be seeded on the better lands where the rainfall is heavier.

TABLE 22.—*Acre yields of varieties of barley grown at the Oklahoma Agricultural Experiment Station, Stillwater; at Ardmore and Carrier; and at the United States Dry Land Field Station, Lawton, in 1 or more of the years 1927–31*

[Data for Stillwater, Ardmore, and Carrier obtained through the courtesy of the Oklahoma Agricultural Experiment Station. The average yield of center rows from quadruplicate nursery plots were taken as the basis for these data. Data for Lawton were obtained through the courtesy of the Division of Dry Land Agriculture]

Variety	C.I. no.	Stillwater												Ardmore						Carrier			
		Number of plots and acre yield										Comparable years and yield in comparison with standard variety named		Number of plots and acre yield				Comparable years and yield in comparison with standard variety named		Number of plots and acre yield (1931)		Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				1930		1931							
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Average yield, 1927–31	Years	Yield	Plots	Yield	Plots	Yield	Average yield, 1927–31	Years	Yield	Plots	Yield	Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*		*Bu.*		*Pct.*
Black Arabian	202			4	28.3	4	2.5						2	55.8											
Greece	221			4	21.1	4	1.2						2	40.4											
Tenkow	646			4	36.5	4	33.1	4	11.4	4	13.6	23.7	4	135.9	4	21.1	4	21.8	21.5	2	122.9	4	46.9	1	93.4
Caliph	983			4	28.5	4	2.3						2	55.8											
Khayyam	1117			4	22.6	4	2.5						2	45.5											
Black Egyptian	1246			4	31.8	4	23.9	4	13.6	4	13.6	20.7	4	119.1	4	15.6	4	19.5	17.6	2	100.6	4	35.5	1	70.7
Syria	1259			4	26.5	4	5.3						2	57.6											
Manchuria	354			4	39.0	4	32.5						2	129.5	4	19.7				1	151.5				
Italiani 52				4	18.0	4	15.4	4	2.3				3	58.4	4	14.4	4	16.9	15.7	2	89.7				
Italiani 16–6684				4	29.6	4	12.8	4	6.1				3	79.4	4	15.6				1	120.0	4	37.0	1	73.7
Italiani 62–6681				4	24.9	4	12.5	4	4.8	4	11.2	13.4	4	76.7	4	14.9	4	15.8	15.4	2	88.0	4	37.2	1	74.1
Italiani 55–6678				4	25.4	4	15.5	4	2.5	4	8.6	13.0	4	74.7	4	13.7	4	18.6	16.2	2	92.6	4	42.0	1	83.7
Italiani 7368–4				4	33.5	4	22.2	4	9.5				3	106.7	4	12.9				1	99.2	4	40.0	1	79.7
Italiani 7368–55				4	25.6	4	14.1	4	7.2	4	7.0	13.5	4	77.4	4	10.7	4	14.4	12.6	2	71.9	4	19.3	1	38.4
Italiani 7368–53				4	29.0	4	17.1	4	6.2	4	8.6	15.2	4	87.5	4	12.7	4	11.8	12.3	2	70.2	4	19.2	1	38.2
Italiani 7368–21				4	32.4	4	21.7	4	14.6				3	112.4	4	16.1				1	123.8	4	32.3	1	64.3
Italiani 7368–27				4	24.6	4	15.7	4	7.9	4	5.5	13.4	4	77.2	4	14.5	4	14.9	14.7	2	84.2	4	36.1	1	71.9
Italiani 7368–62				4	29.9	4	14.9	4	6.2	4	6.1	14.3	4	82.0	4	14.3	4	18.2	16.3	2	93.1	4	22.4	1	44.6
Italiani 7368–84				4	27.9	4	12.5	4	7.7	4	6.3	13.6	4	78.2	4	14.0	4	16.0	15.0	2	86.0	4	16.0	1	31.9
Italiani 7368–76				4	29.4	4	17.6	4	5.3	4	8.1	15.1	4	86.8	4	15.9	4	16.2	16.1	2	92.0	4	22.1	1	44.0
White Smyrna	195			4	29.3	4	16.9	4	11.7	4	13.7	17.9	4	102.9			4	20.4		1	93.2	4	41.6	1	82.9
Manchuria	245			4	35.9	4	14.3	4	10.9	4	7.0	17.0	4	97.8	4	17.9	4	19.3	18.6	2	106.6	4	45.8	1	91.2

Wisconsin Winter	519			4	36.0	4	15.2	4	12.5	4	15.0	19.7	4	113.1	4	17.4	4	25.5	21.5	2	122.9	4	40.9	1	81.5
Cape	557			4	33.1	4	11.3	4	2.8	4	8.6	14.0	4	80.2	4	12.4				1	95.4				
Gatami	575			4	41.4	4	16.3	4	9.3	4	11.2	19.6	4	112.4	4	10.5	4	19.8	15.2	2	86.8	4	26.6	1	53.0
Famesh	616			4	31.8	4	14.0	4	12.3	4	7.5	16.4	4	94.3	4	1.9				1	14.6				
Coast	626			4	25.0	4	17.0	4	4.1	4	8.1	13.6	4	77.9	4	15.1	4	20.5	17.8	2	102.0	4	47.4	1	94.4
Tenkow	646			4	34.6	4	19.3	4	9.6	4	9.1	18.2	4	104.3	4	15.1	4	26.1	20.6	2	118.1	4	48.8	1	97.2
Arlington Awnless	702			4	30.5	4	12.3			4	5.3		3	75.5	4	5.6				1	43.1				
Blackhull	878			4	20.9	4	22.5	4	5.3	4	8.8	14.4	4	82.6	4	18.0	4	14.6	16.3	2	93.4	4	32.5	1	64.7
Nekludowi	1000			4	36.6	4	16.2	4	9.5	4	9.4	17.9	4	103.0	4	7.9	4	20.5	14.2	2	81.4	4	38.2	1	76.1
Cape	1026			4	27.0	4	11.2	4	2.9	4	7.5	12.2	4	69.8	4	10.5	4	25.9	18.2	2	104.3				
Tripoli	1115			4	22.9	4	14.9	4	9.3	4	12.1	14.8	4	85.1	4	11.4	4	18.4	14.9	2	85.4	4	24.7	1	49.2
Featherston	1120			4	39.1	4	21.6	4	6.9	4	11.2	19.7	4	113.2	4	12.5	4	15.1	13.8	2	79.1	4	25.9	1	51.6
Peruvian	1131			4	27.9	4	23.2	4	7.5	4	9.6	17.1	4	98.0	4	7.6	4	26.7	17.2	2	98.3	4	41.9	1	83.5
Entresol	1261			4	45.1	4	17.5	4	4.5	4	11.5	19.7	4	112.9	4	12.5	4	22.9	17.7	2	101.4	4	38.5	1	76.7
Hero	1286			4	39.8	4	17.6	4	10.5	4	16.9	21.2	4	121.8	4	10.1	4	26.7	18.4	2	105.4	4	44.8	1	89.2
Heron	1299			4	31.3	4	22.6	4	9.8	4	7.7	17.9	4	102.6	4	12.7	4	25.1	18.9	2	108.3	4	32.6	1	64.9
Turkistan Winter	711			4	33.4	4	21.1	4	2.8	4	13.1	17.6	4	101.1	4	15.7	4	29.4	22.6	2	129.2	4	58.3	1	116.1
Italiani 7368–68				4	29.6	4	16.9	4	5.3	4	5.3	14.3	4	82.0	4	13.6	4	15.7	14.7	2	84.0	4	20.4	1	40.6
Black Smyrna	191			4	32.9	4	16.6	4	11.6	4	12.1	18.3	4	105.2	4	16.7	4	17.6	17.2	2	98.3	4	34.2	1	68.1
Hankow	192			4	26.5	4	4.9	4	7.7	4	8.6	11.9	4	68.5											
Olonets	198			4	32.3	4	17.6	4	7.6	4	4.9	15.6	4	89.7	4	15.6	4	12.2	13.9	2	79.7	4	21.6	1	43.0
Greece	221			4	16.9	4	1.1						2	32.6											
Finland	581			4	35.4	4	29.0	4	3.4	4	8.4	19.1	4	109.5	4	14.9	4	11.5	13.2	2	75.6	4	31.1	1	62.0
Poda	652			4	31.1	4	17.0	4	6.9	4	9.1	16.0	4	92.1	4	20.9	4	26.1	23.5	2	134.7	4	41.2	1	82.1
Black Algerian	708			4	34.5	4	16.8	4	17.8	4	12.8	20.5	4	117.7	4	11.0	4	14.5	12.8	2	73.1	4	37.6	1	74.9
Turkistan	712			4	44.4	4	5.2						2	89.9	4	10.6				1	81.5				
White Gatami	920			4	44.4	4	16.8	4	11.5	4	11.1	21.0	4	120.4	4	15.4	4	17.8	16.6	2	95.1	4	25.1	1	50.0
Petro	994			4	27.0	4	19.3	4	11.3	4	6.8	16.1	4	92.5	4	15.3	4	19.5	17.4	2	99.7	4	39.3	1	78.3
Abacus	1088			4	27.0	4	8.7						2	64.7	4	2.6				1	20.0				
Calotte	1102			4	44.4	4	23.5	4	6.9	4	5.5	20.1	4	115.4	4	21.4	4	18.0	19.7	2	112.9	4	29.7	1	59.2
Juliaca	1114			4	27.9	4	20.1	4	2.1	4	9.2	14.8	4	85.2	4	14.3	4	27.1	20.7	2	118.6	4	44.5	1	88.6
Corbel	1113			4	32.3	4	12.6	4	7.1	4	9.9	15.5	4	88.9	4	10.6	4	18.1	14.4	2	82.2	4	23.4	1	46.6
Zond	1138			4	30.8	4	15.2	4	12.0	4	9.2	16.8	4	96.6	4	12.9	4	24.5	18.7	2	107.2	4	40.6	1	80.9
Cromlech	1215			4	35.4	4	18.2	4	3.3	4	9.2	16.5	4	95.0	4	12.5	4	22.1	17.3	2	99.1	4	45.6	1	90.8
Turbat	1254			4	33.8	4	9.6	4	7.2	4	9.6	15.1	4	86.5	4	6.9	4	19.3	13.1	2	75.1	4	26.1	1	52.0
Arequipa [1]	1256			4	37.0	4	18.2	4	5.9	4	8.5	17.4	4	100.0	4	13.0	4	21.9	17.5	2	100.0	4	50.2	1	100.0
Theodore	1300			4	27.0	4	19.8	4	12.1	4	9.5	17.1	4	98.3	4	11.4	4	18.1	14.8	2	84.5	4	36.4	1	72.5
Limerick	1302			4	25.8	4	28.1	4	16.9	4	13.6	21.1	4	121.3	4	14.1	4	19.9	17.0	2	97.4	4	34.7	1	69.1
Phoebe	1305			4	27.3	4	23.7	4	11.4	4	9.8	18.1	4	103.7	4	11.1	4	11.7	11.4	2	65.3	4	37.2	1	74.1
Peru	707							4	8.8				1	149.2								4	30.3	1	60.4
Vaughn	1367							4	16.3	4	12.3		2	198.6	4	15.0	4	15.3	15.2	2	286.8	4	43.6	1	86.9
Horn	926							4	5.0	4	18.0		2	159.7	4	9.8	4	12.3	11.1	2	63.3	4	26.1	1	52.0
Trebi	936							4	12.1	4	6.9		2	131.9	4	22.0	4	14.3	18.2	2	104.0	4	41.2	1	82.1
Blackhull	878							4	8.0	4	8.8		2	116.7	4	11.8	4	21.8	16.8	2	96.3	4	31.7	1	63.1
Svansota	1907							4	1.6	4	14.3		2	110.4	4	2.6				1	20.0				
Stavropol	2103							4	3.7	4	13.1		2	116.7	4	15.3	4	33.4	24.4	2	139.5				
Club Mariout	261							4	16.9	4	9.5		2	183.3	4	12.8	4	25.5	19.2	2	109.7	4	39.2	1	78.1
Lion (2238)	923							4	20.3				1	344.1											
Flynn	1311							4	14.9	4	12.5		2	190.3			4	22.2		1	101.4	4	44.8	1	89.2
Winter Club	592							4	8.0				1	135.6											

[1] Standard variety with which others are compared.

TABLE 22.—*Acre yields of varieties of barley grown at the Oklahoma Agricultural Experiment Station, Stillwater; at Ardmore and Carrier; and at the United States Dry Land Field Station, Lawton, in 1 or more of the years 1927–31*—Continued

Variety	C.I. no.	Stillwater												Ardmore						Carrier			
		Number of plots and acre yield										Comparable years and yield in comparison with standard variety named		Number of plots and acre yield				Comparable years and yield in comparison with standard variety named		Number of plots and acre yield (1931)		Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931		Average yield, 1927–31		1930		1931		Average yield, 1927–31							
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield	Plots	Yield	Plots	Yield		Years	Yield	Plots	Yield	Years	Yield
			Bu.		Bu.		Bu.		Bu.		Bu.	Bu.	No.	Pct.		Bu.		Bu.	Bu.	No.	Pct.		Bu.		Pct.
Odessa	182							4	8.1	4	10.6		2	129.9			4	24.0		1	109.6				
White Smyrna	910							4	8.1	4	10.4		2	128.5			4	25.0		1	114.2				
Santrel	937							4	8.6	4	10.5		2	132.6			4	29.0		1	132.4	4	48.7	1	97.0
Meloy	1176							4	4.3	4	7.3		2	80.6											
Coast	690							4	9.0	4	11.3		2	141.0			4	28.4		1	129.7				
Velvet	4252							4	4.6	4	8.0		2	87.5											
Manchuria	2330							4	6.2	4	10.7		2	117.4											
		Lawton																							
Tennessee Winter		1	29.7	1	15.6	2	18.6	2	0.0				4	97.9											
Tennessee Winter (Selection 66)	3546	1	31.8	1	14.8	2	16.9			3	56.7		4	102.1											
Han River [1]	206	1	34.4	1	16.9	2	14.0	2	.0	3	52.4	23.5	5	100.0											
Pidor	901	1	36.5	1	15.6	2	12.8	2	.0	3	51.4	23.3	5	98.8											
Orel	351	1	34.9	1	.0	2	19.0	2	.0	3	36.7	18.1	5	77.0											
Wisconsin Winter	519			2	15.9	4	16.6	[2]14	.0	6	50.4		4	99.5											

[1] Standard variety with which others are compared.

[2] Seedings were made on 7 dates.

OREGON

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The stations from which results are reported in table 23 represent several distinct areas in Oregon. At all stations Trebi is a good variety. It is probably the most satisfactory variety in the section represented by Pendleton and Union. While Trebi produced the highest yield at Moro for the 5-year period, its 10-year average yield is less than that of Club Mariout. Flynn (C.I. 5911) appears to be nearly equal in yield and possesses other desirable qualities. O.A.C. No. 7 (C.I. 2814) and selections from this variety have proved to be very good yielders in both western and eastern Oregon. On bottom land and for winter seeding they excel in western Oregon. Hannchen is a good variety for spring sowing at Corvallis.

In the Pendleton area Trebi is recommended for spring seeding and Winter Club (Utah Winter) for fall seeding. Flynn fits into conditions around Moro, although other varieties may produce equal yields. In western Oregon, O.A.C. No. 7 is recommended for fall seeding, for early spring seeding, and for sowing on bottom land. Selections 1 (C.I. 5953) and 6 (C.I. 5954) from O.A.C. No. 7 are more winter hardy and are more desirable for fall seeding. Hannchen is the best barley for medium and late spring seeding, especially on upland. Ben Beardless is useful on rich soil, as it has a stiff straw.

In western Oregon barley should be sown from October 10 to October 30 for fall seeding and from April 1 to April 30 for spring seeding. The best rate is 100 to 110 pounds per acre. Around Pendleton the preferred seeding date is between March 1 and 15. Seeding on the drier lands should be done as early in the spring as soil conditions permit. Rates of seeding vary in eastern Oregon, being as high as 2¼ bushels in the sections of greatest rainfall and less in the drier areas.

TABLE 23.—*Acre yields of varieties of barley grown at the Oregon Agricultural Experiment Station, Corvallis; at the Sherman County Branch Station, Moro; at the Eastern Oregon Branch Station, Union; at the Harney Valley Branch Station, Burns; and at the Pendleton Field Station in 1 or more of the years 1927–31*

[Data for Corvallis, Union, and Burns furnished through the courtesy of the Oregon Agricultural Experiment Station; those for Moro and Pendleton obtained in cooperation with the station]

Station and variety	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Corvallis:														
Grown on upland:														
Spring barleys:			*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Hannchen [1]	531	7	35.7	7	29.8	7	24.0	7	44.7	4	42.0	35.2	5	100.0
O.A.C. No. 7	2814	3	28.1	3	26.1	3	18.0	3	46.7		40.3	31.8	5	90.4
Peruvian	935	3	28.2	3	28.1	3	18.9	3	41.1	3	36.1	30.5	5	86.5
Trebi	936	3	28.2	3	24.2	3	15.8	3	38.2		33.3	27.9	5	79.3
Ben Beardless	4687			3	23.0	3	22.1	3	46.7		40.5		4	94.2
Atlas	4118			3	22.1	3	16.7						2	72.1
Advance Pedigree	5991			3	22.3	3	27.3	3	36.0				3	86.9
Faust (Montana 1573)	4579			3	23.3	3	19.1	3	17.4				3	60.7
Coast	690			3	26.0								1	87.2
Flynn	1311			3	20.1								1	67.4
Success	4685			3	27.5								1	92.3
Meloy	1176					3	18.3						1	76.3
Arequipa	1256					3	11.1						1	46.3
Blue Hull-less	5990							3	35.0		24.4		2	68.5
Victory	5077									3	45.7		1	108.8
Grown on bottom land:														
Spring barleys:														
Hannchen [1]	531	3	65.4	3	36.1	3	33.3	3	30.4			41.3	4	100.0
O.A.C. No. 7	2814	3	68.1	3	36.9	3	37.3	3	35.7			44.5	4	107.7
Ben Beardless	4687	1	66.7	3	32.3	3	39.4	3	35.0			43.4	4	105.0
Trebi	936			3	34.6	2	35.2	3	33.1				3	103.1
Peruvian	935			3	23.9	3	36.5	3	33.6				3	94.2
Winter barleys:														
O.A.C. No. 7 [1]	2814			4	60.8	7	63.4	7	.0	7	35.3	39.9	4	100.0
O.A.C. No. 7, Selection 1	5953			1	55.8	3	52.8	3	26.3	3	23.0	39.5	4	99.0
O.A.C. No. 7, Selection 2				2	62.9	3	58.3	3	.0				3	97.6
O.A.C. No. 7, Selection 4				2	60.8	3	56.1	3	.0				3	94.1
O.A.C. No. 7, Selection 6	5954			1	71.7	3	78.3	3	20.0	3	26.8	49.2	4	123.4
Pidor	901			1	54.2	3	66.8	3	21.7	3	26.3	42.3	4	106.0
Alaska	4106			1	58.1	3	66.0	3	30.0	3	23.6	44.4	4	111.4
Orel	351			1	54.2	3	55.0	3	21.7	3	24.3	38.8	4	97.3
Wisconsin Winter	2159			1	60.0	3	59.6	3	18.6	3	28.3	41.6	4	104.4
Tennessee Winter	257			1	46.5	3	61.5	3	19.2	3	26.6	38.5	4	96.4
Tennessee Winter Selection	5955			1	57.5	3	61.8	3	25.0	3	25.8	42.5	4	106.6
Winter Club	592			2	46.2	3	76.9	3	31.7	3	16.4	42.8	4	107.3
Moro:														
Club Mariout [1]	261	3	44.4	3	43.9	3	30.0	4	38.4	3	27.6	36.9	5	100.0
Coast	2301	3	40.5	3	38.3								2	89.2
Peru	2302	3	39.5	3	43.5								2	94.0
Meloy Selection 3	4656	3	37.7	3	43.3	3	26.4	4	37.3	3	26.2	34.2	5	92.7
Peruvian	935	3	38.7	3	47.8	3	32.5	4	40.2	3	29.2	37.7	5	102.2
Trebi	936	3	48.9	3	38.1	3	34.9	4	41.5	3	25.8	37.8	5	102.7
Flynn	1311	3	45.8										1	103.2
Arequipa	1256	3	43.8	3	42.6	3	30.0	4	38.6	3	27.4	36.5	5	99.0
Coast (170 B)	4117	3	38.3										1	86.3
Flynn Selection 1	5911	[2] 1	68.8	3	43.0	3	31.5	4	37.5	3	27.5		4	99.7
Pryor	1429	[2] 1	31.3	3	40.0	3	24.3	4	37.0	3	23.5		4	89.2
Chevalier	1419	[2] 1	56.3	3	40.1	3	21.7	4	36.9	3	22.8		4	86.8
Pryor	2359	[2] 1	31.3	3	40.5	3	27.5	4	37.7				3	94.1
Atlas (276 B)	4118			3	40.0	3	28.5	4	37.4	3	23.6		4	92.6

[1] Standard variety with which others are compared.
[2] Grown in small increase plots, not comparable, and therefore not included in average.

TABLE 23.—*Acre yields of varieties of barley grown at the Oregon Agricultural Experiment Station, Corvallis; at the Sherman County Branch Station, Moro; at the Eastern Oregon Branch Station, Union; at the Harney Valley Branch Station, Burns; and at the Pendleton Field Station in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	Number of plots and acre yield										Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931			
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Average yield, 1927–31	Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Union:														
Trebi [1]	936	2	105.4	4	30.2	4	53.3	4	67.2	4	34.4	58.1	5	100.0
Odessa	182	2	89.2	4	31.8	4	48.6	4	56.5	4	37.5	52.7	5	90.7
White Smyrna	658	2	88.2	4	27.4	4	53.9	4	50.3	4	35.4	51.0	5	87.8
Hannchen	531	2	78.2	4	30.8	4	48.2	4	54.5	4	38.8	50.1	5	86.2
Blue	1247	2	93.0	4	30.5	4	59.9	4	60.7	4	38.0	56.4	5	97.1
Coast	2301	2	97.3	4	30.7	4	50.7	4	58.3	4	39.1	55.2	5	95.0
Peruvian	935	2	97.7	4	25.5	4	52.2	4	50.0	4	33.3	51.7	5	89.1
Winter Club	592	2	96.5	4	26.3	4	45.3	4	56.3	4	37.0	52.3	5	99.0
Beardless 3	5992	2	77.6	4	27.1	4	57.7	4	58.6	4	38.8	52.0	5	89.4
Union Beardless	5976	2	61.7	4	23.7	4	44.9	4	73.5	4	49.0	50.6	5	87.0
B×Blue B	5993	2	88.6	4	25.8	4	49.7	4	54.7	4	34.9	50.7	5	87.3
Meloy	1176	2	83.8	4	26.8	4	42.6	4	51.3	4	37.0	48.3	5	83.1
Blue×B–A	4675	2	60.0	4	25.0	4	41.9	4	53.1	4	39.6	43.9	5	75.6
B×White Club C	5994	2	74.0	4	19.0	4	32.0	4	53.2	4	29.4	41.5	5	71.5
Black No. 6	5995	2	66.9	4	16.4	4	44.2	4	46.6	4	23.2	39.5	5	67.9
Unnamed (39–1)	5996	2	83.0	4	16.2	4	35.2	4	40.1	4	26.6	40.2	5	69.2
Nepal	595	2	68.8	4	21.6	4	35.3	4	32.1	4	21.9	35.9	5	61.9
Faust (Montana 1573)	4579	2	58.2	4	21.6	---	---	---	---	---	---	---	2	58.8
O.A.C. No. 7	2814	---	---	4	25.8	4	63.5	4	50.0	4	37.0	---	4	95.2
Steigum	907	---	---	4	23.4	4	44.5	4	44.5	4	34.1	---	4	79.1
Lion	923	---	---	4	27.6	4	42.6	4	39.1	4	30.2	---	4	75.4
Svansota	1907	---	---	---	---	4	32.9	4	46.1	4	31.3	---	3	71.2
Velvet	4252	---	---	---	---	4	22.2	4	26.8	4	26.6	---	3	48.8
Ezond	5064	---	---	---	---	---	---	4	51.9	4	34.9	---	2	85.4
Success Beardless	5997	---	---	---	---	---	---	4	43.0	4	31.5	---	2	73.3
Burns:														
Trebi [1]	936	---	79.7	---	82.7	---	88.9	---	60.7	---	41.6	70.7	5	100.0
Hannchen	531	---	73.5	---	88.7	---	88.0	---	53.7	---	---	---	4	97.4
O.A.C. No. 7	2814	---	---	---	91.8	---	100.5	---	68.9	---	30.4	---	4	106.5
Pendleton:														
Trebi [1]	936	---	---	---	---	3	76.3	3	69.5	3	65.5	70.4	3	100.0
Arequipa	1256	---	---	---	---	3	75.3	---	---	3	62.1	---	2	96.9
Peruvian Selection 1	5912	---	---	---	---	3	67.4	---	---	3	61.8	---	2	91.1
Meloy	1176	---	---	---	---	3	61.5	---	---	3	59.7	---	2	85.5
Flynn Selection 1	5911	---	---	---	---	---	---	3	67.2	3	56.8	---	2	91.9
Club Mariout	261	---	---	---	---	---	---	---	---	3	52.6	---	1	80.3

[1] Standard variety with which others are compared.

PENNSYLVANIA

AGRICULTURAL EXPERIMENT STATION, STATE COLLEGE

CHARLES F. NOLL, *professor of experimental agronomy*

There was little difference in the average yields of the varieties grown at State College, Pa., for the full 5-year period 1927–31 (table 24). Comfort was the leading variety of those grown for the entire period. Two other smooth-awned sorts, Glabron and Velvet, were nearly its equal in yield. Wisconsin Pedigree 38, a new smooth-awned variety, showed much promise for a shorter period, as it has at many places. In the previous 5 years Featherston and Alpha

produced the highest yields. The 10-year average of Alpha is rather high, indicating that 2-rowed barley would be a satisfactory crop in Pennsylvania. This sort, however, is very susceptible to smut.

The experiment station has been recommending Wisconsin Pedigree 5, Comfort, and Velvet, and it has found that early seeding is advisable. The average date of seeding in the vicinity of State College is about April 24. In southeastern Pennsylvania the most favorable time is about 2 weeks earlier than this date, and, in the northern counties, about 2 weeks later. The usual rate of seeding is 2 bushels per acre.

TABLE 24.—*Acre yields of varieties of barley grown at the Pennsylvania Agricultural Experiment Station, State College, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Pennsylvania Agricultural Experiment Station]

Variety	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Michigan Two-Row	2782	2	47.5	2	22.0	2	18.9	2	44.1				4	103.7
Wisconsin Pedigree 5	1272	2	37.9	2	30.0	2	20.2	2	32.9	3	25.1	29.2	5	92i.9
Oderbrucker	836	2	41.7	2	26.2	2	23.5	2	31.4	3	24.1	29.4	5	93.4
Featherston	1120	2	38.5	2	23.6	2	20.5	2	31.7				4	89.4
Alpha	959	2	46.0	2	20.5	2	21.2	2	39.5	3	23.6	30.2	5	95.9
Glabron	4577	2	37.0	2	22.2	2	22.8	2	41.5	3	27.2	30.1	5	95.8
Comfort [1]	4578	2	36.5	2	22.4	2	26.4	2	42.5	3	29.5	31.5	5	100.0
Velvet	4252	2	37.3	2	21.5	2	25.1	2	38.7	3	29.3	30.4	5	96.6
Swiss Spring	5900	2	32.3	2	25.8	2	23.7	2	37.3	3	29.1	29.6	5	94.2
Spartan	5027			2	18.1	2	20.1	2	35.7				3	80.9
Wisconsin Pedigree 38	5105							2	51.9	3	32.9		2	117.8

[1] Standard variety with which others are compared.

SOUTH CAROLINA

AGRICULTURAL EXPERIMENT STATION, CLEMSON COLLEGE

W. B. ROGERS, *assistant agronomist*

Hooded and awnless varieties are popular with farmers in the Southeastern States. As shown in table 25, the farmer must sacrifice a certain part of his yield in exercising this preference. The best of the nonbearded sorts, according to these tests, is South Carolina 206C. The Tennessee hooded varieties are well suited to conditions and are extensively grown in South Carolina. Tennessee Beardless, one of the Tennessee hooded barleys, and Tennessee Winter (Winter Bearded) are the varieties usually recommended. The latter also is recommended for pasture and winter grazing where the residue is to be turned under for some other crop. October is the most favorable month for seeding, and 1½ to 2 bushels per acre is the best rate of seeding.

TABLE 25.—*Acre yields of varieties of barley grown at the South Carolina Agricultural Experiment Station, Clemson College, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the South Carolina Agricultural Experiment Station]

Variety	C.I. no.	South Carolina no.	Number of plots and acre yield [1]								Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1929		1930		1931		Average yield, 1927–31		
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Winter Bearded			10	39.4	10	21.4	10	28.2	12	79.4	42.1	4	124.5
Awnless [2]	4693	206C	10	22.9	10	30.4	10	29.2	12	52.8	33.8	4	100.0
Do	4694	206L	10	18.5	10	28.0	10	27.2	9	34.6	27.1	4	80.0
Hooded	5956	188	10	17.9	10	15.5	10	36.8	13	32.8	25.8	4	76.1
Tennessee Beardless			10	23.1	10	14.6	10	17.6	13	25.2	20.1	4	59.5
Kirkland Beardless	5957						10	17.1	13	36.7		2	65.6
Wood Beardless (hooded)									12	38.8		1	73.5

[1] No yields were recorded for 1928, as the crop was destroyed by hail.
[2] Standard variety with which others are compared.

SOUTH DAKOTA

STATE COLLEGE OF AGRICULTURE, BROOKINGS

K. H. KLAGES, *associate agronomist in charge of cereal breeding*, and A. N. HUME, *agronom.st*

While many of the varieties reported in table 26 have produced good yields at Brookings, S.Dak., the standard variety is Odessa. This variety has given a consistent performance over a long period and should not be displaced until it is fully evident that some other variety is really better. The results at Redfield have been carried on for too short a time to be conclusive, but they indicate a transition toward Highmore conditions where two-rowed varieties and the smooth-awned hybrids are high-yielding sorts. The two-rowed varieties have also produced high yields at Ardmore. The zero yields at Highmore and Ardmore in 1931 were due to drought augmented by grasshoppers. At Newell the only varieties that produced yields at all comparable with those of Trebi were White Smyrna and Chevalier. The yields from Trebi exceeded each of these in 4 years out of 5. Vaughn and the hybrids ×239 and ×241 were badly injured by spring frosts at Redfield in 1931.

Odessa is recommended for the eastern part of the State, and Horn, Ace, and Lion×Manchuria for the central area. Trebi should be grown under irrigation in the western portion.

Barley should be seeded early. Sowings later than April 15 are likely to result in reduced yield. It is recommended that 6 pecks per acre be sown in the eastern part of the State. A rate of 5 pecks per acre is sufficient in the central and western section except under irrigation, when 8 pecks should be used.

TABLE 26.—*Acre yields of varieties of barley grown at the South Dakota Agricultural Experiment Station, Brookings; at the Eureka and Highmore substations; the United States Dry Land Field Station, Ardmore; the Belle Fourche Field Station, Newell; and in the United States cereal field experiments at Redfield, in 1 or more of the years 1927–31*

Data for Brookings, Eurkea, and Highmore obtained through the courtesy of the South Dakota Agricultural Experiment Station; for Ardmore, through the courtesy of the Division of Dry Land Agriculture; for Newell, through the courtesy of the Division of Western Irrigation Agriculture; and for Redfield, in cooperation with the station and the Division of Forage Crops and Diseases]

Station and variety	C.I. no.	South Dakota no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		Bu.		Bu.		Bu.		Bu.	Bu.		Pct.
Brookings:															
Odessa [1]	182	182	3	68.8	3	56.3	3	42.7	3	40.7	3	9.8	43.7	5	100.0
Oderbrucker	1529	1180	3	53.5	3	47.9	3	38.1	3	29.8	3	3.8	34.6	5	79.3
Manchuria	643	105	3	54.1	3	52.6	3	25.0	3	30.5				4	77.8
Improved Manchuria	2330	1338	3	53.1	3	52.6	3	36.5	3	32.5				4	83.8
White Gatami	920	839	3	58.3	3	47.9	3	45.4	3	44.6	3	10.0	41.2	5	94.5
Black Gatami	575	122	3	54.1	3	41.7	3	41.2	3	42.7				4	86.2
White Smyrna	195	28	3	53.1	3	43.8	3	29.7	3	30.9				4	75.5
Horsford	507	294	3	33.3	3	40.7	3	5.8	3	29.6				4	52.5
Gold	1145	460	3	50.1	3	52.6	3	22.9	3	34.6				4	76.8
Nepal	262	262	3	42.7	3	43.3	3	21.9	3	27.3				4	64.8
Poppenheim	314	442	3	32.2	3	36.0	3	13.0	3	27.5				4	52.1
Minsturdi	1556	1245	3	47.9	3	46.9	3	40.6	3	37.1	3	8.8	36.3	5	83.1
Ace	1853	1173	3	59.0	3	40.7	3	28.2	3	34.6	3	9.7	34.4	5	78.9
July	1563	1270	3	54.1	3	51.1	3	37.0	3	29.2				4	82.2
Glabron	4577	1292	3	62.5	3	52.6	3	31.8	3	41.5	3	6.7	39.0	5	89.4
Comfort	4578	1304	3	70.8	3	52.1	3	35.0	3	34.0				4	92.0
Lion×Coast		1342	3	67.7	3	64.6	3	35.4	3	30.4				4	95.0
Velvet	4252	1286	3	51.0	3	50.7	3	33.9	3	35.4				4	82.0
Lion×Manchuria	6001	1340	3	56.2	3	50.6	3	48.0	3	40.5	3	10.6	41.2	5	94.3
Svansota	1907	1285	3	47.9	3	48.5	3	26.1	3	31.5				4	73.9
Bon Ami	4664	1300	3	67.7	3	63.6	3	47.4	3	39.0				4	104.4
Sandrel	937	1301	3	68.8	3	62.5	3	41.7	3	40.4				4	102.4
Horn	926	1299	3	65.6	3	69.3	3	36.5	3	33.8	3	4.6	42.0	5	96.1
Trebi	936	1298	3	69.8	3	69.3	3	28.7	3	34.4	3	9.7	42.4	5	97.1
White Smyrna×Svanhals		1344	3	59.4	3	57.3	3	39.1	3	37.3				4	92.6
Featherston	911	1306	3	57.5	3	62.1	3	30.8	3	35.0				4	88.9
Hero	1286	1303		63.5	3	48.3	3	27.1	3	50.0				4	88.2
Alpha	959	1305	3	54.2	3	66.2	3	25.0	3	31.7				4	84.9
(Success×Gatami)×(Arlington Awnless×Hanna)		1360	3	38.5	3	37.0	3	32.9	3	29.8				4	66.3
New Era	5108	1355							3	27.9	3	3.1		2	61.4
Coast×Lion	6002	1343									3	7.7		1	78.6
Binder	1909	1269									3	1.0		1	10.2
Hannchen	531	20									3	.7		1	7.1
Eureka:															
Velvet	4252	1286	3	54.5		(2)	3	17.3	3	21.5				3	104.1
White Smyrna×Svanhals		1344	3	60.0			3	14.3	3	17.0				3	101.9
Odessa [1]	182	182	3	49.6			3	15.7	3	24.3	3	16.3	26.5	4	100.0
Lion×Coast		1342	3	52.1			3	13.3	3	18.2				3	93.3
Glabron	4577	1290									3	13.5		1	82.8
Lion×Manchuria	6001	1340									3	15.3		1	93.9
Horn	926	1299									3	14.3		1	87.7
Coast×Lion	6002	1343									3	14.6		1	89.6
Binder	1909	1269									3	14.2		1	87.1
Hannchen	531	20									3	10.8		1	66.3
Highmore:															
Odessa [1]	182	182	3	36.7	3	6.4	3	28.9	3	22.3	3	.9	19.0	5	100.0
Coast	690	126	3	41.3	3	6.8	3	32.6	3	23.9				4	110.9
Manchuria	643	105	3	40.2	3	8.6	3	29.5	3	21.5				4	105.8
White Smyrna	195	28	3	35.0	3	2.1	3	33.9	3	18.8				4	95.2

[1] Standard variety with which others are compared.

[2] No yields are reported for 1928 at Eureka, as hail destroyed the crop.

TABLE 26.—*Acre yields of varieties of barley grown at the South Dakota Agricultural Experiment Station, Brookings; at the Eureka and Highmore substations; the United States Dry Land Field Station, Ardmore; the Belle Fourche Field Station, Newell; and in the United States cereal field experiments at Redfield, in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	South Dakota no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Highmore—Continued.				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Horsford	507	294	3	31.0	3	8.6	3	19.8	3	18.3				4	82.4
Poppenheim	314	442	3	21.4	3	5.7	3	18.2	3	17.6				4	66.7
Oderbrucker	1529	1180	3	41.1	3	9.4	3	28.1	3	21.7		.0	20.1	5	105.4
Minsturdi	1556	1245	3	40.5	3	7.2	3	27.1	3	23.9		2.2	20.2	5	106.0
July	1563	1270	3	39.6	3	6.7	3	36.5	3	18.7				4	107.6
Binder	1909	1269	3	43.3	3	11.1	3	24.7	3	22.3	3	.5	20.4	5	107.0
Lion×Manchuria	6001	1340	3	41.8	3	6.0	3	39.1	3	28.0	3	2.1	23.4	5	122.9
White Smyrna×Svanhals		1344	3	38.6	3	1.5	3	35.9	3	25.3				4	107.4
Coast×Lion	6002	1343	3	46.5	3	4.9	3	29.2	3	28.2	3	2.2	22.2	5	116.6
Lion×Coast		1342	3	45.0	3	11.4	3	29.2	3	17.7				4	109.5
Do		1341	3	45.8	3	9.4	3	19.8	3	21.1				4	101.9
Rex	1388	1268	3	38.4	3	5.4	3	21.1	3	13.0				4	82.6
Gold×Nepal		1345	3	36.5	3	9.0	3	16.4	3	12.5				4	78.9
Nepal×Manchuria		1339	3	28.7	3	5.8	3	17.4	3	12.7				4	68.5
Ace	1853	1173	3	39.2	3	2.8	3	39.1	3	23.8	3	2.3	21.4	5	112.6
Svansota	1907	1285	3	44.1	3	6.8	3	33.6	3	19.5				4	110.3
Velvet	4252	1286	3	47.5	3	10.2	3	21.9	3	26.3				4	112.3
Glabron	4577	1292			3	12.7	3	24.3	3	29.3	3	1.6		4	116.1
Horn	926	1299			3	12.5	3	27.4	3	25.6	3	.0		4	112.0
Comfort	4578	1304			3	11.3	3	23.4	3	26.9				3	106.9
Trebi	936	1298			3	8.9	3	18.8	3	23.3	3	1.2		4	89.2
White Gatami	920	889										2.6		1	288.9
Hannchen	531	20										.0		1	
New Era	5108	1355										.0		1	
Spartan	5027	1352										3.0		1	333.3
Ardmore:															
Odessa [1]	182		3	73.3	3	20.5	3	4.2	3	16.9	3	2.8	23.5	5	100.0
Hannchen	531		3	64.9	3	17.7	3	3.5	3	3.1	3	.0	17.8	5	75.8
White Gatami	920		3	49.0	3	17.0	3	11.1						3	78.7
Horsford	507		3	52.4	3	16.3	3	6.9	3	15.1				4	78.9
White Smyrna	658		3	67.0	3	25.4	3	18.4	3	24.1	3	.0	27.0	5	114.6
Coast	690		3	50.0	3	21.2	3	17.0	3	17.0	3	.0	21.0	5	89.4
Horn	926		3	76.0	3	25.7	3	12.5	3	10.7	3	2.1	25.4	5	107.9
Trebi	936		3	68.1	3	19.4	3	12.9	3	16.3	3	2.8	23.9	5	101.5
Ace	1853				3	24.7	3	17.7	3	26.8	3	5.2		4	167.6
Vaughn	1367						3	11.5	3	25.3	3	5.2		3	175.7
Glabron	4577						3	10.1	3	13.9	3	2.8		3	112.1
Charlottetown 80	2732						3	9.4	3	1.9				2	53.6
Velvet	4252								3	[2] 7.8	3	1.0		2	44.7
Vance	4585										3	4.9		1	175.0
Dryland	5673										3	1.0		1	35.7
New Era	5108										3	1.7		1	60.7
Newell:															
Trebi [1]	936		3	30.9	3	54.9	3	49.5	3	81.7	3	27.1	48.8	5	100.0
Coast	690		3	26.0	3	41.7	3	33.3	3	68.7				4	78.2
Hannchen	531		3	24.0	3	42.4	3	46.9	3	52.0	3	17.4	36.5	5	74.8
Chevalier II	200		3	41.0	3	50.4	3	49.3	3	57.3	3	20.8	43.8	5	89.6
Minsturdi	1556		3	27.4	3	34.4	3	43.1	3	49.4				4	71.1
Luth	908		3	19.8	3	36.6	3	41.7	3	60.4				4	73.0
White Smyrna	195		3	30.2	3	52.1	3	42.7	3	73.4	3	30.9	45.9	5	93.9
Horsford	507		3	16.3	3	27.6	3	33.3	3	40.6				4	54.3
Nepal	595		3	16.0	3	26.0	3	35.8	3	41.7				4	55.1
Comfort	4578								3	57.8	3	7.6		2	60.1
Velvet	4252								3	44.2	3	5.9		2	46.0
New Era (×240)	5108										2	13.0		1	48.0
×239	5674										3	9.0		1	33.2
×241	5675										3	9.4		1	34.7

[1] Standard variety with which others are compared.

[2] Velvet barley was sown 2 weeks later than other varieties because of late arrival of seed. This probably reduced its yield.

TABLE 26.—*Acre yields of varieties of barley grown at the South Dakota Agricultural Experiment Station, Brookings; at the Eureka and Highmore substations; the United States Dry Land Field Station, Ardmore; the Belle Fourche Field Station, Newell; and in the United States cereal field experiments at Redfield, in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	South Dakota no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Redfield:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Hannchen	531						3	10.9	2	19.3	3	3.3	11.2	3	57.3
Svanhals	187						3	7.6	2	18.4	3	2.6	9.5	3	48.9
Nepal	262						3	6.2	1	21.0	3	10.4	12.5	3	64.3
Wing Pedigree	1177						3	9.1	2	24.7	3	10.2	14.7	3	75.2
Trebi	936						3	11.2	2	33.9	3	11.4	18.8	3	96.6
Oderbrucker	1174						3	3.6	2	12.6	3	5.9	7.4	3	37.8
Manchuria	244						3	9.1	2	25.5	3	15.1	16.6	3	85.0
New Era (×240)	5108						3	8.4	2	33.1	3	12.6	18.0	3	92.5
Odessa [1]	182						3	12.1	2	32.0	3	14.4	19.5	3	100.0
Dryland	5673						3	11.0	2	35.1	3	24.8	23.6	3	121.2
White Smyrna	658						3	13.6	2	38.0	3	20.7	24.1	3	123.6
Vaughn	1367								2	42.1	3	23.1		2	140.5
New Composite Cross	5461								1	32.3	3	10.4		2	92.0
Glabron	4577								2	28.3	3	15.9		2	95.3
Velvet	4252								2	25.3	3	10.4		2	76.9
×244	5676								2	19.8	3	2.1		2	47.2
×239	5674								2	27.6	3	6.5		2	73.5
×241	5675								2	25.8	3	4.7		2	65.7

[1] Standard variety with which others are compared.

TENNESSEE

AGRICULTURAL EXPERIMENT STATION, KNOXVILLE

C. A. MOOERS, *Director*

Yields were secured in only 4 of the 5 years, 1927–31, at Knoxville, Tenn. (table 27). The entire crop winter-killed in 1928. The highest yield was obtained from Tennessee Winter Selection 52, which is similar to Union Winter in appearance. Union Winter has long been a standard variety and is still recommended for growing. Many farmers, however, prefer the hooded varieties, Tennessee Beardless 5 and Tennessee Beardless 6.

Barley should be seeded the latter part of September or early October. A seeding rate of 8 pecks per acre is recommended. Under favorable conditions slightly less seed might be used for Union or Tennessee Winter, but not for the hooded varieties.

TABLE 27.—*Acre yields of varieties of barley grown at the Tennessee Agricultural Experiment Station, Knoxville, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Tennessee Agricultural Experiment Station]

Variety	C.I. no.	Number of plots and acre yield [1]								Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1929		1930		1931				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Percent*
Union Winter [2]	583	2	35.2	2	30.0	2	6.4	5	56.6	25.6	5	100.0
Beardless 5	3384	2	25.3	2	25.8	2	1.3	5	40.5	18.6	5	72.5
Nakano Wase	754	2	22.9								1	65.1
Tennessee Winter Selection 52	3543	2	37.3	2	30.0	2	15.6	5	57.3	28.0	5	109.4
Tennessee Winter Selection 66	3546	2	31.3	2	25.7						3	87.4
Wisconsin Winter	2159	2	33.9	2	25.8						3	91.6
Orel	351	2	27.9	2	8.9						3	56.4

[1] The 1928 crop was winter-killed.
[2] Standard variety with which others are compared.

TEXAS

P. C. MANGELSDORF, *agronomist, Texas Agricultural Experiment Station, College Station*, and P. B. DUNKLE, *Superintendent, substation no. 6, Denton*

Barley is not an important crop in Texas, and the available information on it is rather fragmentary. From table 28 it appears that barleys of the Tennessee Winter group are more dependable than any others at Denton, but winter-killing was experienced in 1927, 1928, and 1929, and there was a total loss of the crop in 1928. At San Antonio the consistently superior yields of Vaughn are encouraging. On the basis of experiments at Denton and of data supplied through the courtesy of the station at San Antonio, Finley or strains of Tennessee Winter are recommended for northeastern Texas, and Vaughn is recommended for sections to the west.

Winter seeding from November to January is recommended for the San Antonio section. For the Denton section of northern Texas, winter barley should be sown from October 1 to 20 and spring barley about the first of February. Spring varieties, and not winter types, should be used for spring seedings. For western Texas spring barley is preferred. In the Panhandle most of the barley is sown about February 15. Winter barley is grown to some extent along the Oklahoma border, but it frequently winter-kills in the Panhandle. The rate of 2 bushels per acre is suggested for northeastern Texas, while 6 pecks is sufficient for most of the areas to the west.

TABLE 28.—*Acre yields of varieties of barley grown at Denton, Tex., substation no. 6, and at the United States San Antonio Field Station in one or more of the years 1927–31*

[Data for Denton obtained through the courtesy of the Texas Agricultural Experiment Station and for San Antonio through the courtesy of the Division of Western Irrigation Agriculture]

Station and variety	Station no.	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		Bu.		Bu.		Bu.		Bu.	Bu.		Pct.
Denton:															
Finley (local)		5901								25.1	6	67.4		2	126.9
Coast	15829	690									6	58.0		1	[1]47.2
Tennessee Winter	15841	257								32.1	6	45.8		2	106.9
Stavropol	15828	2103									6	44.8		1	113.7
Atlas [1]	15840	4118								33.5	6	39.4		2	100.0
Club Mariout	15842	261								26.1	6	38.2		2	88.2
Vaughn	15830	1367								38.2	6	34.6		2	99.9
Bailey		5902						38.3							
Tennessee Winter Selection 643–33			2	31.6	3	[2].0		30.5							
Tennessee Winter Selection 643–0		5914	2	35.6	3	[2].0		30.8							
Spring barley	7368–4							20.4							
Do	7368–2							12.8							
Italian	6681			[2].0		[2].0		17.6							
San Antonio:															
Hannchen	3162	531	1	14.4	3	15.1	3	17.8	3	[2].0	3	52.7	20.0	5	80.7
Orel	3148	351	1	5.3	3	6.0								2	39.2
Wisconsin Winter	3149	2159	1	1.6	3	6.0	3	15.4						3	51.8
Tennessee Winter	3150	3543	1	.9	3	6.8	3	14.4						3	49.8
Do	3151	3546	1	1.9	3	9.7	3	14.7						3	59.2
Texas Winter [1]	3152	554	1	19.7	3	9.1	6	15.6	3	11.1	3	68.4	24.8	5	100.0
Stavropol	3161	2103	1	13.8	3	7.5	3	18.3						3	89.2
Vaughn	3403	1367					3	22.7	3	11.3	3	91.2		3	131.7
Trebi	3405	936					3	8.3	3	9.3	3	54.6		3	75.9

[1] Standard variety with which others are compared.
[2] Zero yields due to winter-killing.

UTAH

AGRICULTURAL EXPERIMENT STATION, LOGAN

R. J. EVANS, *professor of agronomy*

Limited data are available from Utah for the 5-year period reported in table 29. Trebi is the standard variety of the irrigated sections of the State, and it will be noted that its yield in the nursery was significantly exceeded by no other variety for the 5 years. In general, the other high-yielding sorts are of north African origin. Sacramento and Algerian showed promise in the 2 years grown. Trebi is recommended for the irrigated lands. It should be seeded in April at the rate of 2 bushels per acre.

NEPHI SUBSTATION, NEPHI

A. F. BRACKEN, *Superintendent*

Variety tests have not been conducted in recent years at Nephi, but experience covering many years has shown Bulgarian to be the best of the many tried. Bulgarian is a winter variety and should be seeded in September at the rate of 7 pecks per acre.

TABLE 29.—*Acre yields of varieties of barley grown at the Agricultural Experiment Station, Logan, Utah, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Utah Agricultural Experiment Station. These results are based on replicated nursery rows]

Variety	C.I. no.	Colorado no.	Number of plots and acre yield												Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931		Average yield, 1927–31			
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield			Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*			*Pct.*
Atlas	4118	-----	4	92.4	4	89.4	4	59.0	4	91.2	4	66.0	79.6		5	101.8
Coast	690	-----	4	81.7	4	88.4	4	59.2	4	63.6	4	62.5	71.1		5	90.9
Colsess	2792	-----	4	75.6	4	71.3	4	62.2	4	66.6	4	66.4	68.4		5	87.5
Trebi [1]	936	-----	4	87.9	4	87.9	4	63.3	4	88.1	4	63.9	78.2		5	100.0
Unnamed	-----	3063	4	80.9	4	84.5	4	63.3	4	96.6	4	69.5	79.0		5	100.9
Do	-----	3064	4	82.9	4	80.0	4	60.8	4	94.3	4	59.3	75.5		5	96.5
Do	-----	3066	4	81.1	4	79.3	4	53.2	4	82.7	4	56.3	70.5		5	90.2
Do	-----	3070	4	83.2	4	69.2	4	54.3	4	76.2	4	57.8	68.1		5	87.1
Do	-----	3080	4	67.5	4	76.5	4	59.4	4	99.6	4	58.3	72.3		5	92.4
Do	-----	3086	4	71.7	4	76.5	4	57.9	4	77.0	4	59.4	68.5		5	87.6
Do	-----	3124	4	73.0	4	74.0	4	59.8	4	82.0	4	61.8	70.1		5	89.6
Do	-----	3127	4	75.3	4	83.0	4	63.0	4	93.9	4	58.4	74.7		5	95.5
Do	-----	3135	4	75.9	4	72.1	4	60.7	4	86.6	4	62.1	71.5		5	91.4
Do	-----	3154	4	88.1	4	84.6	4	65.6	4	99.0	4	60.6	79.6		5	101.7
Do	-----	3168	4	86.6	4	77.3	4	58.2	4	90.4	4	57.0	73.9		5	94.5
Do	-----	3178	4	65.9	4	81.1	4	50.2	4	86.4	4	62.0	69.1		5	88.4
Do	-----	3192	4	88.0	4	88.5	4	52.0	4	89.0	4	59.9	75.5		5	96.5
Do	-----	3195	4	67.9	4	67.8	4	58.1	4	83.6	4	59.8	67.4		5	86.2
Do	-----	3216	4	88.1	4	74.9	4	61.2	4	104.4	4	62.8	78.3		5	100.1
Do	-----	3116	-----	-----	-----	-----	-----	-----	4	82.5	4	56.8	-----		2	91.6
Han River	206	-----	-----	-----	-----	-----	-----	-----	4	87.7	4	59.9	-----		2	97.1
White Smyrna	910	-----	-----	-----	-----	-----	-----	-----	4	80.5	4	54.4	-----		2	88.8
Algerian	1179	-----	-----	-----	-----	-----	-----	-----	4	106.0	4	60.8	-----		2	109.7
Golden Pheasant	2488	-----	-----	-----	-----	-----	-----	-----	4	70.3	4	39.3	-----		2	72.1
Bonfarik	3393	-----	-----	-----	-----	-----	-----	-----	4	82.1	4	65.1	-----		2	96.8
Harlan 81A	3625	-----	-----	-----	-----	-----	-----	-----	4	98.4	4	60.4	-----		2	104.5
Baker	975	-----	-----	-----	-----	-----	-----	-----	4	100.2	4	56.0	-----		2	102.8
Scarab	995	-----	-----	-----	-----	-----	-----	-----	4	83.6	4	62.8	-----		2	96.3
Arequipa	1256	-----	-----	-----	-----	-----	-----	-----	4	89.1	4	57.8	-----		2	96.6
Beldi Giant	2777	-----	-----	-----	-----	-----	-----	-----	4	82.6	4	63.9	-----		2	96.4
Molu	3210–2	-----	-----	-----	-----	-----	-----	-----	4	52.0	4	45.9	-----		2	64.4
Do	3210–4	-----	-----	-----	-----	-----	-----	-----	4	52.7	4	50.4	-----		2	67.8
Rhodesia	3339	-----	-----	-----	-----	-----	-----	-----	4	88.4	4	61.1	-----		2	98.4
Carre 48	3388	-----	-----	-----	-----	-----	-----	-----	4	94.2	4	64.6	-----		2	104.5
Abyssinia	3906–3	-----	-----	-----	-----	-----	-----	-----	4	84.5	4	52.3	-----		2	90.0
Ankober	3914–3	-----	-----	-----	-----	-----	-----	-----	4	58.5	4	51.3	-----		2	72.2
Abyssinia	3918–1	-----	-----	-----	-----	-----	-----	-----	4	55.8	4	46.3	-----		2	67.2
Makfud	3921–2	-----	-----	-----	-----	-----	-----	-----	4	55.0	4	53.3	-----		2	71.3
Indian	3934	-----	-----	-----	-----	-----	-----	-----	4	68.6	4	52.5	-----		2	79.7
Erivan	4091	-----	-----	-----	-----	-----	-----	-----	4	71.8	4	59.3	-----		2	86.3
Khuram	4148–2	-----	-----	-----	-----	-----	-----	-----	4	61.0	4	58.6	-----		2	78.7
Sebzavar	4156–2	-----	-----	-----	-----	-----	-----	-----	4	78.7	4	61.0	-----		2	91.9
Bokhara	4162	-----	-----	-----	-----	-----	-----	-----	4	46.7	4	51.5	-----		2	64.6
China	4206–1	-----	-----	-----	-----	-----	-----	-----	4	46.4	4	58.0	-----		2	68.7
Tachira 2	4208	-----	-----	-----	-----	-----	-----	-----	4	79.8	4	60.2	-----		2	92.1
Abyssinia	4221	-----	-----	-----	-----	-----	-----	-----	4	59.1	4	50.8	-----		2	72.3
Chili	4223–1	-----	-----	-----	-----	-----	-----	-----	4	72.8	4	56.0	-----		2	84.7
Abyssinia	4225–2	-----	-----	-----	-----	-----	-----	-----	4	64.4	4	55.5	-----		2	78.9
Do	5021	-----	-----	-----	-----	-----	-----	-----	4	60.8	4	54.6	-----		2	75.9
India	5023	-----	-----	-----	-----	-----	-----	-----	4	84.2	4	50.0	-----		2	88.3
Abyssinia	5022	-----	-----	-----	-----	-----	-----	-----	4	56.4	4	51.8	-----		2	71.2
Peru	707	-----	-----	-----	-----	-----	-----	-----	4	90.2	4	65.3	-----		2	102.3
Sacramento	4108	-----	-----	-----	-----	-----	-----	-----	4	111.0	4	59.8	-----		2	112.4
Lyallpur E	3403	-----	-----	-----	-----	-----	-----	-----	-----	-----	4	61.3	-----		1	95.9
Club Mariout	261	-----	-----	-----	-----	-----	-----	-----	-----	-----	4	58.6	-----		1	91.7
Invincible	590	-----	-----	-----	-----	-----	-----	-----	-----	-----	4	39.5	-----		1	61.8
Hero	1286	-----	-----	-----	-----	-----	-----	-----	-----	-----	4	63.3	-----		1	99.1
Vaughn	1367	-----	-----	-----	-----	-----	-----	-----	-----	-----	4	55.4	-----		1	86.7
Modjo	3212–2	-----	-----	-----	-----	-----	-----	-----	-----	-----	4	50.8	-----		1	79.5

[1] Standard variety with which others are compared.

VIRGINIA

ARLINGTON EXPERIMENT FARM, ROSSLYN

During the 5 years 1927–31 Esaw was the leading variety at the Arlington Experiment Farm, and, as may be seen in table 30, one of the Tennessee Winter Selections (C.I. 3534) exceeded and another (C.I. 3545) equaled Wisconsin Winter (C.I. 2159) in yield. Wisconsin Winter, however, is a dependable variety with a long performance record behind it. Wisconsin Winter and Esaw are recommended for seeding on farms in the Potomac area. Tennessee Winter, likewise, has some market qualities that make it desirable, and it is a logical selection where a kernel similar to Manchuria is desired. In 1930, yields were materially reduced by drought, and in 1931 there was a crop failure due to the severe drought.

Barley should be seeded before the end of September, the best rate being 2 bushels per acre.

TABLE 30.—*Acre yields of varieties of barley grown at the Arlington Experiment Farm, Rosslyn, Va., in 1 or more of the years 1927–31*

Variety	C.I. no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931 [1]				
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu*	*Bu.*		*Pct.*
Wisconsin Winter [2]	2159	12	34.3	11	30.2	6	51.0	9	15.3	---	0	26.2	5	100.0
Tennessee Winter	257	2	33.0	2	30.0	1	44.2	1	16.3	---	0	24.7	5	94.4
Tenkow	646	2	34.7	2	26.0	1	46.7	1	14.2	---	0	24.3	5	93.0
Scottish Pearl	277	2	35.2	2	27.3	1	47.1	2	18.1	---	0	25.5	5	97.6
Pidor	901	2	29.7	2	24.8	1	34.0	2	15.4	---	0	20.8	5	79.4
Orel	351	2	31.2	2	16.5	1	36.5	2	14.0	---	0	19.6	5	75.1
Han River	2163	2	24.5	2	29.6	1	36.9	2	21.1	---	0	22.4	5	85.7
Wisconsin Winter	2167	2	22.2	2	29.4	1	40.7	2	23.3	---	0	23.1	5	88.4
Nakano Wase	754	2	5.4	2	19.6	1	47.3	1	4.8	---	0	15.4	5	58.9
Do	2166	2	2.6	---	------	---	------	---	------	---	------	------	1	7.6
Tennessee Winter Selection 52	3543	2	15.1	2	28.2	1	31.3	1	20.0	---	0	18.9	5	72.3
Alaska	4106	2	30.8	2	32.6	1	37.8	2	24.5	---	0	25.1	5	96.1
Tennessee Winter Selection 66	3546	2	35.2	2	28.2	1	37.5	2	21.0	---	0	24.4	5	93.2
Tennessee Winter Selection 61	3545	2	35.7	2	29.6	1	45.3	2	20.6	---	0	26.2	5	100.3
Tennessee Winter Selection 12	3534	2	42.0	2	30.0	1	51.5	2	17.9	---	0	28.3	5	108.1
Mechanical Mixture	4115	2	25.3	2	29.2	1	61.1	1	14.4	---	0	26.0	5	99.4
Composite Cross	4116	2	22.4	2	21.9	1	49.2	1	21.3	---	0	23.0	5	87.8
Tennessee Beardless 5	3384	2	32.5	2	32.3	1	26.3	---	------	---	------	------	3	78.9
Tennessee Beardless 6	2746	2	34.9	2	32.3	1	23.3	1	13.8	---	0	20.9	5	79.7
Esaw (754–A)	4690	2	56.5	2	34.1	1	65.0	2	21.6	---	0	35.4	5	135.5
Trebi	936	---	------	---	------	1	21.3	1	3.2	---	------	------	2	37.0
New Composite Cross (spring)	5461	---	------	---	------	---	------	1	8.8	---	0	------	2	57.5
Composite Cross (winter)	5530	---	------	---	------	---	------	1	11.1	---	0	------	2	72.5

[1] Zero yields due to drought. [2] Standard variety with which others are compared.

WASHINGTON

AGRICULTURAL EXPERIMENT STATION, PULLMAN

E. G. SCHAFER, *agronomist*

The results at Pullman, Wash., are in accord with those previously reported. As may be seen in table 31, Beldi Giant, Blue, and Trebi are the leading spring varieties and are satisfactory in the Palouse

region. Winter Club has long been recognized as the most dependable winter variety, and it is recommended for fall seeding.

The same three spring varieties have produced the highest yields at Prosser. In order of importance at this place, however, they are Trebi, Beldi Giant, and Blue.

At Lind the four varieties tested did not differ greatly in yield. Beldi Giant, however, proved to be the best of the four.

Barley should be sown as early in the spring as conditions permit. On the drier lands of the Big Bend country, sowing should be done in March or early April. In the better-watered parts of the Palouse, April is the most satisfactory sowing time for spring barleys, while winter barley, in the more favorable areas, should usually be sown during the latter part of September. Rates of seeding vary from 5 pecks on the drier soils to 8 pecks on the best of the Palouse.

TABLE 31.—*Acre yields of varieties of barley grown at the Washington Agricultural Experiment Station, Pullman; at the Irrigation Branch Station, Prosser; and at the Adams Branch Experiment Station, Lind, Wash., in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Washington Agricultural Experiment Station]

Station and variety	C.I. no.	Washington no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Pullman:															
Spring-sown:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Beldi Giant	2777	967	4	72.2	4	66.9	4	66.1	4	64.9	4	52.1	64.4	5	102.2
Blue	1247	973	4	65.7	4	66.0	4	71.7	4	64.9	4	62.4	66.1	5	104.9
Eureka	1250	958	4	43.8	4	52.4	4	50.6	4	40.0	4	44.9	46.3	5	73.5
Colsess	2792	2410	4	38.0	4	39.3	4	51.1	4	47.8	4	56.9	46.6	5	73.9
Horsford	1775	873	4	52.3	4	58.8	4	64.7	4	50.7	4	48.6	55.0	5	87.2
Trebi [1]	936	1776	4	58.0	4	67.6	4	70.7	4	65.6	4	53.5	63.1	5	100.0
Mechanical Mixture	4115	2485	4	60.0	4	53.2	4	62.0	4	50.5	4	68.5	58.8	5	93.3
New Composite Cross (spring)	5461	------	---	------	---	------	---	------	4	44.3	4	52.2	------	2	81.0
Fall-sown:															
Winter Club	592	957	4	52.9	4	48.2	4	57.7	4	67.3	4	56.0	56.4	5	89.4
Wisconsin Winter	519	971	4	55.7	4	48.6	4	44.2	4	64.4	4	50.6	52.7	5	83.5
Prosser:															
Blue [1]	1247	973	---	50.6	---	50.0	---	46.6	---	39.6	---	55.0	48.4	5	100.0
Beldi Giant	2777	967	---	47.9	---	45.0	---	51.9	---	42.1	---	------	------	4	100.1
Horsford	1775	873	---	43.3	---	42.7	---	44.1	---	31.7	---	------	------	4	86.6
Trebi	936	1176	---	60.4	---	46.0	---	52.2	---	41.2	---	------	------	4	107.0
Mariout	------	2571	---	46.7	---	------	---	------	---	------	---	------	------	1	92.3
Do	------	2572	---	44.6	---	------	---	------	---	------	---	------	------	1	88.1
Lind:															
Beldi Giant [1]	2777	967	---	15.8	---	26.6	---	11.4	---	3.5	---	5.6	12.6	5	100.0
Flynn	1311	------	---	13.7	---	26.2	---	9.4	---	4.6	---	5.8	11.9	5	94.9
Meloy	1176	1343	---	15.2	---	25.8	---	12.2	---	3.5	---	3.9	12.1	5	96.3
California	1279	959	---	14.1	---	23.7	---	13.1	---	1.9	---	4.5	11.5	5	91.1

[1] Standard variety with which others are compared.

WEST VIRGINIA

AGRICULTURAL EXPERIMENT STATION, MORGANTOWN

R. J. GARBER, *head, Department of Agronomy*

The yields of barley in West Virginia reported in table 32 have almost the same relationship as those obtained in the previous 5-year period. This means that Alpha has a clear record of superiority over a period of 10 years and is recommended.

Seeding should be done early in April. Six pecks ordinarily furnish sufficient seed for 1 acre. Since Alpha has larger seed than six-rowed varieties, an additional peck is desirable when growing this variety.

TABLE 32.—*Acre yields of varieties of barley grown at the West Virginia Agricultural Experiment Station, Morgantown, in some or all of the years 1927–31*

[Data obtained through the courtesy of the West Virginia Agricultural Experiment Station]

Variety	C.I. no.	Number of plots and acre yield										Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931			
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Average yield, 1927–31	Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Manchuria	244	4	44.8	4	19.5	4	39.9	4	37.7	4	39.0	36.2	5	90.9
Chevalier	278	4	32.5	4	13.2	4	45.4	4	48.8	4	38.8	35.7	5	89.8
Alpha [1]	959	4	43.9	4	21.6	4	51.0	4	40.9	4	41.6	39.8	5	100.0
Featherston	1120	4	34.9	4	21.0	4	38.9	4	36.0	4	24.1	31.0	5	77.8
Oderbrucker	1174	4	35.5	4	23.2	4	37.8	4	40.4	4	35.2	34.4	5	86.5
Himalaya	620	4	23.2	----	------	----	------	----	------	----	------	------	1	52.8
Nepal	262	4	17.2	----	------	----	------	----	------	----	------	------	1	39.2
Wisconsin Pedigree	835	4	33.6	4	20.9	4	35.2	4	38.3	4	35.6	32.7	5	82.2
Wisconsin Pedigree 38	5105	----	------	----	------	----	------	----	------	4	37.9	------	1	91.1

[1] Standard variety with which others are compared.

WISCONSIN

UNIVERSITY OF WISCONSIN, MADISON

B. D. LEITH, *professor of agronomy, College of Agriculture*

Plot tests at Madison, Wis., during the 5 years 1927–31 have been devoted largely to the evaluation of smooth-awned varieties. The yields shown in table 33, together with the experiences of farmers, have led officials of the Experiment Station to recommend Wisconsin Pedigree 38. This variety, in addition to its smooth awns, is recommended because of its resistance to stripe and because it is less affected by scab than Oderbrucker.

Barley is usually sown in Wisconsin immediately after the sowing of wheat and oats. This varies from April 1 to May 7, but the average date is about the third week in April. The common rate of seeding is 2 bushels per acre, but 1½ bushels is the rate recommended for Wisconsin Pedigree 38.

TABLE 33.—*Acre yields of varieties of barley grown at the Wisconsin Agricultural Experiment Station, Madison, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Wisconsin Agricultural Experiment Station]

Variety	C.I. no.	Wisconsin no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Oderbrucker	4666	Pedigree 5–1	[1] 1	37.7	1	49.0	1	29.5	1	46.1	1	39.5	40.4	5	97.1
Smooth White	4659	×39–2	1	53.8	1	40.3	---	---	---	---	---	---	---	2	105.8
Do	4660	×39–9	1	53.1	---	---	---	---	---	---	---	---	---	1	112.5
Wisconsin Pedigree 37 [2]	5028	Pedigree 37	1	47.2	1	41.7	1	43.7	1	40.7	1	34.6	41.6	5	100.0
Korsbyg	918	97–3	1	41.9	---	---	---	---	---	---	---	---	---	1	88.8
July	1563	---	1	41.4	---	---	---	---	---	---	---	---	---	1	87.7
Colsess	2792	---	1	34.5	---	---	---	---	---	---	---	---	---	1	73.1
Short-Awned	4661	×10–6–4–1	1	29.1	---	---	---	---	---	---	---	---	---	1	61.7
Comfort	4578	---	1	42.6	1	47.8	1	42.7	1	45.4	1	34.8	42.7	5	102.6
Velvet	4252	---	1	42.5	1	49.5	1	37.5	1	38.6	1	34.0	40.4	5	97.2
Glabron	4577	---	1	40.6	1	54.2	1	33.4	1	47.3	1	45.8	44.3	5	106.4
Wisconsin Hybrid	5944	×39–9–3–4	---	---	1	67.2	1	44.1	1	46.7	1	36.2	---	4	120.8
Wisconsin Pedigree 38	5105	Pedigree 38	---	---	1	52.2	1	47.7	1	45.5	1	37.8	---	4	114.0
Wisconsin Hybrid	5945	×57–12–4–13	---	---	1	42.9	1	47.4	1	59.1	1	34.4	---	4	114.4
Trebi	936	---	---	---	---	---	1	28.3	1	34.2	1	34.2	---	3	81.3
Alpha	959	---	---	---	---	---	---	---	1	40.1	1	37.2	---	2	102.7
Spartan	5027	---	---	---	---	---	---	---	1	38.2	1	37.6	---	2	100.7
Manchurian	5946	116	---	---	---	---	---	---	---	---	1	34.5	---	1	99.7

[1] Varieties were grown in single plots, with every other plot through the field a check, and the yields were corrected to the behavior of the check.

[2] Standard variety with which others are compared.

WYOMING

AGRICULTURAL EXPERIMENT STATION, LARAMIE

GLENN HARTMAN, *associate agronomist*

The varietal yields from Wyoming reported in table 34 are closely in accord with those published in 1929. Trebi and Coast are again the leading varieties at Archer and Sheridan. For irrigated conditions the results at Laramie indicate that Horn, Charlottetown 80, and Trebi are satisfactory varieties. While the yield from Odessa was rather high, it is not recommended at this time, due to its tendency to shatter under arid conditions and also to the fact that Laramie is the point farthest west where high yields have been secured from this variety. Charlottetown 80 was not grown in the previous period, but the other three varieties had already shown promise at Laramie.

On dry lands 5 pecks to the acre, and, under irrigation, 8 pecks, is usually a satisfactory rate of seeding. The best time to seed is from April 15 to May 1. Where grown for grain, Coast and Trebi are recommended for dry land. Where the straw is to be utilized, Horn, Smyrna, and Vaughn are suggested.

TABLE 34.—*Acre yields of varieties of barley grown at the Wyoming Agricultural Experiment Station, Laramie; at the Cheyenne Experiment Farm, Archer; and at the Sheridan Field Station, Sheridan, in 1 or more of the years 1927–31*

[Data for Laramie obtained through the courtesy of the Wyoming Agricultural Experiment Station; for Archer and Sheridan through the courtesy of the Division of Dry Land Agriculture, in cooperation with the station]

Station and variety	C.I. no.	Number of plots and acre yield										Number of years grown and yield in comparison with standard variety for comparable years	
		1927		1928		1929		1930		1931			
		Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Average yield, 1927–31	Years	Yield
			Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Laramie (irrigated):														
O.A.C. 21	1470	1	90.3	1	27.5	1	50.9	1	68.5	1	63.4	60.1	5	81.9
Charlottetown 80	2732	1	100.2	1	47.9	1	93.1	1	62.0	1	79.9	76.6	5	104.4
Manchuria	----	1	80.4	1	28.3	1	53.6	1	83.7	----	----	----	4	80.5
White Smyrna	658	1	103.2	1	59.9	1	81.7	1	62.6	1	55.5	72.6	5	98.9
Hannchen	531	1	103.6	1	57.6	1	70.6	1	68.5	1	56.0	71.3	5	97.1
Trebi [1]	936	5	108.2	4	34.0	6	84.2	6	79.2	6	61.3	73.4	5	100.0
Coast	690	1	69.9	1	44.6	1	94.8	1	94.2	1	57.3	72.2	5	98.3
Nepal	595	1	92.7	1	50.2	1	55.5	1	67.6	1	73.5	67.9	5	92.5
Odessa	182	1	96.6	1	24.6	1	105.8	1	121.1	1	65.6	82.7	5	112.8
Beldi Giant	2777	1	83.3	1	36.1	1	73.9	1	66.7	1	64.8	65.0	5	88.5
Colsess	2792	1	72.9	1	13.1	1	56.0	1	57.7	1	58.3	51.6	5	70.3
Horn	926	1	113.8	1	54.0	1	88.6	1	71.8	1	96.3	84.9	5	115.7
Atlas	4118	----	----	----	----	----	----	1	43.3	1	32.3	----	2	53.8
Glabron	4577	----	----	----	----	----	----	----	----	1	66.4	----	1	108.3
Archer:														
White Smyrna	658	4	31.9	4	7.3	4	14.7	----	----	----	----	----	3	69.4
Do	910	4	35.0	4	16.5	4	16.8	4	9.1	4	22.4	20.0	5	96.5
Flynn	1311	4	32.7	4	22.5	4	20.2	----	----	----	----	----	3	97.0
Coast	690	4	35.3	4	18.1	4	21.1	4	14.6	4	17.9	21.4	5	103.5
Trebi [1]	936	4	37.1	4	18.7	4	21.9	4	9.3	4	16.4	20.7	5	100.0
Himalaya	620	4	26.3	4	9.5	4	17.0	4	3.8	4	13.8	14.1	5	68.1
Black Hull-less	1106	4	25.4	4	9.5	4	14.4	----	----	----	----	----	3	63.4
Hannchen	531	4	29.3	4	16.2	4	19.1	4	7.6	4	16.1	17.7	5	85.4
Franconian	680	4	24.7	4	11.1	----	----	----	----	----	----	----	2	64.2
Horn	926	4	32.9	4	16.5	4	18.8	4	8.0	4	12.3	17.7	5	85.6
Meloy	1176	4	34.3	4	18.7	4	15.1	4	6.1	4	18.0	18.4	5	89.2
Colsess	2792	4	24.3	4	16.5	4	11.4	----	----	----	----	----	3	67.2
Selection 8–3	----	----	----	2	14.0	3	17.0	4	7.6	4	13.3	----	4	78.3
Selection 8–1	----	----	----	2	10.9	4	13.9	4	4.1	4	14.2	----	4	65.0
Selection 5	----	----	----	1	7.3	4	12.9	4	7.2	4	16.0	----	4	65.5
Selection 3	----	----	----	1	6.7	4	9.7	4	5.0	4	15.0	----	4	54.9
Selection 3–1	----	----	----	----	----	1	9.6	----	----	----	----	----	1	43.8
Selection 9–1	----	----	----	----	----	2	16.1	4	10.7	4	11.1	----	3	79.6
Selection 8–2	----	----	----	----	----	2	13.3	4	5.7	4	15.1	----	3	71.6
Vaughn	1367	----	----	----	----	----	----	4	11.2	4	23.6	----	2	135.4
Sheridan:														
White Smyrna	195	3	44.4	3	63.1	----	----	----	----	----	----	----	2	72.9
Hannchen	531	3	48.9	3	74.2	3	37.8	3	21.7	3	13.1	39.1	5	77.7
Svanhals	187	3	57.2	3	76.4	3	36.4	3	20.0	3	16.4	41.3	5	81.9
Club Mariout	261	3	55.8	3	73.3	----	----	----	----	----	----	----	2	87.5
Coast	690	3	51.7	3	84.7	3	46.7	3	35.0	3	13.0	46.2	5	91.7
Trebi [1]	936	3	61.7	3	85.8	3	46.4	3	40.0	3	18.1	50.4	5	100.0
Manchuria	244	3	44.4	3	73.0	----	----	----	----	----	----	----	2	79.6
Flynn	1311	3	46.7	3	74.4	3	40.8	3	38.9	3	18.6	43.9	5	87.1
Horn	926	3	61.1	3	79.7	3	44.2	3	36.1	3	12.0	46.6	5	92.5
Meloy	1176	3	57.8	3	64.7	3	34.1	3	41.4	3	15.3	42.7	5	84.6
Colsess	2792	3	56.1	3	68.9	3	26.9	3	27.5	3	11.1	38.1	5	75.6
Nepal	595	3	47.2	3	55.8	3	27.5	3	24.7	3	5.0	32.0	5	63.6
Faust	4579	3	43.6	3	51.4	----	----	----	----	----	----	----	2	64.4
California White Hull-less	----	3	41.1	3	50.3	----	----	----	----	----	----	----	2	62.0
Vaughn	1367	----	----	----	----	3	34.2	3	36.7	3	20.8	----	3	87.8
Glabron	4577	----	----	----	----	3	34.7	3	35.6	3	15.8	----	3	82.4
Velvet	4252	----	----	----	----	3	39.4	3	21.9	3	12.5	----	3	70.6
Charlottetown 80	2732	----	----	----	----	3	30.6	----	----	----	----	----	1	65.9

[1] Standard variety with which others are compared.

ALBERTA

EXPERIMENTAL STATION, LETHBRIDGE

W. H. FAIRFIELD, *Superintendent*

Varieties are tested at Lethbridge, Alberta, under both dry-land and irrigated conditions. The results of these tests are reported in table 35. Of the varieties grown for the full period, Trebi produced the highest yield both on dry land and under irrigation. The two-rowed varieties Hannchen (C.I. 531) and Horn also gave creditable showings under both conditions. Regal was promising for the 2 years that it was grown. Trebi and Hannchen are recommended for this section of Alberta. They should be seeded in April or the early part of May at the rate of 8 pecks per acre on both irrigated and nonirrigated land.

EXPERIMENTAL STATION, LACOMBE

F. H. REED, *Superintendent*

During the period 1927–31, 27 varieties were tested at Lacombe, Alberta, for 1 or more years (table 35). No yields are reported for 1930. Of the varieties grown for 4 years, Trebi produced by far the highest yield. Hannchen (C.I. 531), a two-rowed variety, was second in yield with an average of 72.3 bushels, as compared with 86 bushels for Trebi. Both of these varieties are recommended for this district. They should be seeded in early May at the rate of 8 pecks per acre.

TABLE 35.—*Acre yields of barley varieties grown at the experimental stations at Lethbridge, Lacombe, Beaverlodge, and Fort Vermilion, Alberta, and at the University of Alberta, Edmonton, in 1 or more of the years 1927–31*

[Data for the first 4 stations were obtained through the courtesy of the Dominion Experimental Farms and for Edmonton through the courtesy of the University of Alberta. Plots consist of blocks of 5-rod rows each, of which the 3 central rows were harvested]

Station and variety	C.I. no.	Canadian accession no.	Number of plots and acre yield												Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931		Average yield, 1927–31			
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield			Years	Yield
Lethbridge:																
Under irrigation:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*			*Pct.*
Bark	2793	703	4	64.1	4	84.4	4	50.9	4	73.0	4	82.2	70.9		5	96.3
Bearer (Ottawa 475)	4707	704	4	56.3	4	63.0	4	79.1	4	81.3	4	96.3	75.2		5	102.1
Canadian Thorpe	740	816	4	56.3	4	88.0	4	82.3	4	70.3	4	78.2	75.0		5	101.9
Cape	557	708	4	65.9	4	40.2	4	75.0	4	94.7	4	106.7	76.5		5	103.9
Duckbill (Ottawa 57)	1916	826	4	53.2	4	70.3	4	61.8	4	59.7	4	67.9	62.6		5	85.0
Gold	1145	829	4	55.6	---	------	4	74.3	4	92.1	4	99.7	------		4	105.0
Hannchen	531	837	4	43.5	4	83.1	4	84.2	4	90.7	4	95.1	79.3		5	107.7
Himalayan (Ottawa 59)	4838	765	4	57.3	4	55.5	4	65.4	4	89.6	4	90.5	71.7		5	97.3
Horn	926	1078	4	68.5	4	56.3	4	88.7	4	91.6	4	75.3	76.1		5	103.3
Mensury (Ottawa 60)	4696	730	4	65.9	4	67.0	4	46.9	---	------	---	------	------		3	83.4
O.A.C. 21 [1]	1470	734	4	80.9	4	61.9	4	72.7	4	86.5	4	66.2	73.6		5	100.0
O.A.C. 21 (Saskatchewan 228)	4708	735	4	79.6	4	59.9	4	73.0	4	79.1	4	76.2	73.6		5	99.9
Star	1701	748	4	69.1	4	64.0	4	43.0	4	70.1	4	62.9	61.8		5	83.9
Trebi	936	753	4	76.3	4	62.4	4	78.1	4	109.7	4	91.7	83.6		5	113.6
Velvet	4252	755	4	62.9	4	81.2	4	67.8	4	91.4	4	72.1	75.1		5	102.0
Plumage Archer	5033	806	---	------	---	------	4	67.4	4	91.2	4	78.9	------		3	105.4
Colsess	2792	772	---	------	---	------	---	------	4	91.4	4	83.2	------		2	114.3
Glabron	4577	718	---	------	---	------	---	------	4	96.3	4	93.9	------		2	124.6
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	4	74.2	4	75.1	------		2	97.8
Hanna	5975	1075	---	------	---	------	---	------	4	100.7	4	99.1	------		2	130.8
Regal	5030	742	---	------	---	------	---	------	4	121.2	4	107.8	------		2	150.0
White Smyrna	195	859	---	------	---	------	---	------	---	------	4	94.1	------		1	142.1
Dry-land tests:																
Bark	2793	703	4	46.0	4	41.8	4	15.8	4	34.3	4	17.5	31.1		5	97.5
Bearer (Ottawa 475)	4707	704	4	34.1	4	50.1	4	12.7	4	37.8	4	26.0	32.1		5	100.8
Canadian Thorpe	740	816	4	32.4	4	32.8	4	18.0	4	33.4	4	18.8	27.1		5	84.9
Cape	557	708	4	40.7	4	45.6	4	36.2	4	36.8	4	27.7	37.4		5	117.3
Duckbill (Ottawa 57)	1916	826	4	25.1	4	36.2	4	13.8	4	26.2	4	13.8	23.0		5	72.2
Gold	1145	829	4	38.5	---	------	4	27.6	4	35.3	4	32.9	------		4	123.6
Hannchen	531	837	4	40.0	4	57.0	4	32.1	4	42.2	4	37.0	41.7		5	130.7
Himalayan (Ottawa 59)	4838	765	4	23.1	4	40.1	4	27.5	4	26.2	4	26.6	28.7		5	90.0
Horn	926	1078	4	50.5	4	45.8	4	31.4	4	39.7	4	39.6	41.4		5	129.9
Mensury (Ottawa 60)	4696	730	4	31.0	4	40.5	4	20.6	---	------	---	------	------		3	91.1
O.A.C. 21 [1]	1470	734	4	33.6	4	50.7	4	16.8	4	35.4	4	22.9	31.9		5	100.0
O.A.C. 21 (Saskatchewan 228)	4708	735	4	26.9	4	45.0	4	16.0	4	34.7	4	27.3	30.0		5	94.0
Star	1701	748	4	27.1	4	56.0	4	16.3	4	40.7	4	30.6	34.1		5	107.1
Trebi	936	753	4	42.4	4	55.6	4	37.9	4	38.2	4	36.8	42.2		5	132.3
Velvet	4252	755	4	30.5	4	43.6	4	23.2	4	30.1	4	25.8	30.6		5	96.1
Plumage Archer	5033	806	---	------	---	------	4	12.8	4	33.1	4	22.7	------		3	91.3
Hanna	5975	1075	---	------	---	------	---	------	4	42.8	4	41.9	------		2	145.3
Regal	5030	742	---	------	---	------	---	------	4	37.0	4	33.0	------		2	120.1
Colsess	2792	772	---	------	---	------	---	------	---	------	4	30.0	------		1	131.0
Glabron	4577	718	---	------	---	------	---	------	---	------	4	25.6	------		1	111.8
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	---	------	4	20.3	------		1	88.6
Lacombe:																
Bark	2793	703	4	32.1	4	22.9	4	29.6	---	------	4	66.7	37.8		4	60.1
Bearer (Ottawa 475)	4707	704	4	43.7	4	41.8	4	71.2	---	------	4	109.0	66.4		4	105.6
Canadian Thorpe	740	816	4	50.3	4	32.0	4	62.2	---	------	4	118.1	65.7		4	104.3
Cape	557	708	4	87.9	4	39.4	4	48.8	---	------	4	103.0	69.8		4	110.9
Charlottetown 80	2732	817	4	53.4	4	33.5	4	57.4	---	------	4	81.4	56.4		4	89.7
Duckbill (Ottawa 57)	1916	826	4	33.3	4	26.4	4	31.4	---	------	4	75.4	41.6		4	66.2

[1] Standard variety with which others are compared.

TABLE 35.—*Acre yields of barley varieties grown at the experimental stations at Lethbridge, Lacombe, Beaverlodge, and Fort Vermilion, Alberta, and at the University of Alberta, Edmonton, in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	Canadian accession no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Lacombe—Continued.				Bu.		Bu.		Bu.		Bu.		Bu	Bu.		Pct.
Early Chevalier (Ottawa 51)	2725	821	4	55.1	4	29.8	4	45.8	---	------	4	67.7	49.6	4	87.8
Eureka	1250	773	4	39.7	4	19.0	4	43.3	---	------	4	76.9	44.7	4	71.1
Gold	1145	829	4	67.1	4	34.0	4	72.5	---	------	4	73.6	61.8	4	98.2
Hannchen	531	837	4	74.0	4	40.1	4	77.2	---	------	4	97.7	72.3	4	114.8
Himalayan (Ottawa 59)	4838	765	4	62.6	4	35.3	4	38.4	---	------	4	87.1	55.9	4	88.8
Manchurian (Ottawa 50)	4832	726	4	64.9	4	39.1	4	43.9	---	------	4	94.6	60.6	4	96.3
Mensury (Ottawa 60)	4696	730	4	71.8	4	37.5	4	58.0	---	------	4	98.7	66.5	4	105.7
O.A.C. 21 [1]	1470	734	4	63.3	4	36.5	4	60.4	---	------	4	91.5	62.9	4	100.0
Star	1701	748	4	61.5	4	42.5	4	62.8	---	------	4	98.8	66.4	4	105.5
Stella (Ottawa 58)	4851	750	4	67.1	4	34.7	4	49.0	---	------	4	100.6	62.9	4	99.9
Success	4840	783	4	63.3	4	23.7	4	26.1	---	------	4	68.1	45.3	4	72.0
Swedish Chevalier	4837	818	4	59.4	4	31.4	4	58.2	---	------	4	88.0	59.3	4	94.2
Trebi	936	753	4	99.5	4	43.6	4	68.7	---	------	4	132.2	86.0	4	136.7
Velvet	4252	755	4	67.0	4	31.5	4	48.0	---	------	4	103.8	62.6	4	99.4
Colsess	2792	772	---	------	---	------	4	68.7	---	------	4	85.7	------	2	101.6
Glabron	4577	718	---	------	---	------	4	55.1	---	------	4	94.0	------	2	98.2
Plumage Archer	5033	806	---	------	---	------	4	63.6	---	------	4	59.8	------	2	81.2
Regal	5030	742	---	------	---	------	4	80.4	---	------	4	122.0	------	2	133.2
Binder	4703	810	---	------	---	------	---	------	---	------	4	80.8	------	1	88.3
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	---	------	4	77.0	------	1	84.2
Sans Barb	5970	746	---	------	---	------	---	------	---	------	4	130.0	------	1	142.1
Beaverlodge:															
Albert (Ottawa 54)	4852	701	4	31.0	---	------	---	------	4	49.1	4	25.6	------	3	55.1
Bearer (Ottawa 475)	4707	704	4	73.5	4	55.9	4	54.1	4	74.9	4	34.8	58.6	5	102.7
Canadian Thorpe	740	816	4	73.3	4	62.2	4	35.8	4	50.9	4	20.3	48.5	5	84.9
Charlottetown 80	2732	817	4	75.5	4	57.7	4	45.0	4	58.5	4	32.6	53.9	5	94.3
Duckbill (Ottawa 57)	1916	826	4	60.7	4	44.5	4	39.4	4	49.7	4	21.9	43.2	5	75.7
Early Chevalier (Ottawa 51)	2725	821	4	74.0	4	55.6	4	36.7	4	60.1	4	41.5	53.6	5	93.8
Eureka	1250	773	4	63.8	4	41.2	4	49.0	4	63.5	4	41.8	51.9	5	90.8
Gold	1145	829	4	70.8	4	69.8	4	45.0	4	75.1	4	28.5	57.8	5	101.3
Hannchen (Saskatchewan 229)	4841	837	4	71.9	4	70.5	4	50.5	4	83.7	4	42.8	63.9	5	111.9
Lapland	5973	877	4	78.4	4	65.5	4	38.9	4	72.4	4	45.7	60.2	5	105.4
Mensury (Ottawa 60)	4696	730	4	72.7	---	------	4	37.8	4	66.6	4	44.2	------	4	94.3
O.A.C. 21 [1]	1470	734	4	68.3	4	50.8	4	42.7	4	71.9	4	51.8	57.1	5	100.0
Pearl	4834	780	4	61.9	4	49.3	4	47.5	4	57.0	4	40.8	51.3	5	89.8
Star	1701	748	4	80.0	4	74.3	4	51.5	4	78.5	4	46.7	66.2	5	115.9
Stella (Ottawa 58)	4851	750	4	68.5	4	50.1	4	33.0	4	61.1	4	36.1	49.8	5	87.1
Trebi	936	753	4	84.5	4	80.8	4	48.2	4	88.6	4	47.3	69.9	5	122.4
Velvet	4252	755	---	------	4	43.0	4	33.6	4	63.1	4	24.6	------	4	75.6
Plumage Archer	5033	806	---	------	---	------	---	------	4	66.5	4	29.2	------	2	77.4
Regal	5030	742	---	------	---	------	---	------	4	76.2	4	41.3	------	2	95.0
Binder	4703	810	---	------	---	------	---	------	---	------	4	64.2	------	1	123.9
Colsess	2792	772	---	------	---	------	---	------	---	------	4	44.7	------	1	86.3
Glabron	4577	718	---	------	---	------	---	------	---	------	4	43.9	------	1	84.7
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	---	------	4	40.0	------	1	77.2
Manchurian (Ottawa 50)	4832	726	---	------	---	------	---	------	---	------	4	44.1	------	1	85.1
Fort Vermilion: [2]															
Albert (Ottawa 54)	4852	701	4	52.5	4	46.3	4	71.2	4	52.5	4	56.3	55.8	5	102.1
Charlottetown 80	2732	817	4	46.5	4	31.3	4	61.3	4	66.5	4	67.5	54.6	5	100.0
Eureka	1250	773	4	56.3	4	35.0	4	53.8	4	61.3	4	38.8	49.0	5	89.8
Gold	1145	829	4	53.8	4	28.8	4	68.8	4	67.5	4	59.0	55.6	5	101.8
Hull-less White	5972	785	4	47.5	4	32.5	4	50.0	4	58.8	4	47.5	47.3	5	86.6
Manchurian (Ottawa 50)	4832	726	4	61.3	4	37.5	4	68.8	4	65.0	4	60.0	58.5	5	107.2
O.A.C. 21 [1]	1470	734	4	62.5	4	41.7	4	63.8	4	62.5	4	42.5	54.6	5	100.0

[1] Standard variety with which others are compared.
[2] Yields at Fort Vermilion were obtained from 1/100-acre plots.

TABLE 35.—*Acre yields of barley varieties grown at the experimental stations at Lethbridge, Lacombe, Beaverlodge, and Fort Vermilion, Alberta, and at the University of Alberta, Edmonton, in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	Canadian accession no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Fort Vermilion—Contd.				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Success	4840	783	4	51.3	4	48.8	4	62.5	4	55.0	4	50.0	53.5	5	98.0
Canadian Thorpe	740	816	---	------	---	------	4	72.5	4	73.8	4	50.0	------	3	116.3
Hannchen	531	837	---	------	---	------	4	67.5	4	71.3	4	66.6	------	3	121.7
Plumage Archer	5033	806	---	------	---	------	4	70.0	4	70.0	4	67.5	------	3	122.9
Star	1701	748	---	------	---	------	4	65.0	4	50.0	4	60.0	------	3	103.7
Edmonton:[3]															
Bark	2793	703	4	46.3	4	40.3	4	42.7	4	9.1	4	40.8	35.8	5	76.3
Bearer (Ottawa 475)	4707	704	4	52.0	4	90.1	4	56.5	4	24.3	4	28.3	50.2	5	107.0
Canadian Thorpe [4]	740	816	4	55.4	4	37.1	4	33.0	4	11.0	4	50.0	37.3	5	79.4
Charlottetown 80	2732	817	4	59.3	4	56.9	4	48.7	4	28.5	4	50.5	48.8	5	103.9
Eureka	1250	773	4	38.5	4	40.2	4	28.9	4	37.3	4	27.4	34.5	5	73.4
Hannchen	531	837	4	65.0	4	60.6	4	59.7	4	39.9	4	48.1	54.7	5	116.4
Horn	926	1078	4	58.2	4	68.3	4	54.5	4	30.0	4	48.1	51.8	5	110.3
Manchurian (Ottawa 50)	4832	726	4	37.4	4	59.2	4	27.4	4	17.2	4	43.9	37.0	5	78.8
O.A.C. 21 [1]	1470	734	4	36.4	4	65.4	4	39.7	4	36.5	4	56.8	47.0	5	100.0
Trebi	936	753	4	87.4	4	68.6	4	57.0	4	32.7	4	54.9	60.1	5	128.0
Hybrid 265×O.A.C. 21 (H–19–146)	-----	1089	4	88.4	4	68.9	4	56.0	4	43.5	4	63.9	64.1	5	136.6
Gold	1145	829	---	------	4	37.0	4	36.3	4	9.4	4	39.4	------	4	61.5
Alberta Beardless	4865	874	---	------	---	------	---	------	4	16.0	4	32.4	------	2	51.9
Colsess	2792	772	---	------	---	------	---	------	4	34.9	4	50.2	------	2	91.2
Comfort	4578	712	---	------	---	------	---	------	4	35.8	4	52.4	------	2	94.5
Duckbill (Ottawa 57)	1916	826	---	------	---	------	---	------	4	11.5	4	40.9	------	2	56.2
Glabron	4577	718	---	------	---	------	---	------	4	29.0	4	49.3	------	2	83.9
Minsturdi	1556	732	---	------	---	------	---	------	4	30.7	4	50.0	------	2	86.5
New Era	5108	721	---	------	---	------	---	------	4	25.2	4	38.0	------	2	67.7
Peatland	5267	722	---	------	---	------	---	------	4	17.5	4	53.4	------	2	76.0
Plumage Archer	5033	1004	---	------	---	------	---	------	4	22.5	4	55.6	------	2	83.7
Regal	5030	742	---	------	---	------	---	------	4	34.7	4	54.9	------	2	96.0
Spartan	5027	860	---	------	---	------	---	------	4	22.5	4	43.9	----	2	71.2
Star	1701	748	---	------	---	------	---	------	4	42.8	4	56.9	------	2	106.9
Velvet	4252	755	---	------	---	------	---	------	4	22.0	4	52.4	------	2	79.7
Vaughn (Alberta stock no. I–30–1)	1367	1090	---	------	---	------	---	------	4	17.8	4	18.6	------	2	39.0
Atlas	4118	702	---	------	---	------	---	------	---	------	4	51.7	------	1	91.0
California Mariout	1455	728	---	------	---	------	---	------	---	------	4	33.3	------	1	58.6
Sacramento	4108	744	---	------	---	------	---	------	---	------	4	54.6	------	1	96.1
Sol (Sixty-Day)	5031	782	---	------	---	------	---	------	---	------	4	39.7	------	1	69.9

[1] Standard variety with which others are compared.
[3] Yields at Edmonton were taken from center rows of 3 rod-row plots.
[4] Canadian Thorpe was heavily infected with barley stripe in 1928, 1929, and 1930.

EXPERIMENTAL STATION, BEAVERLODGE

W. D. ALBRIGHT, *Superintendent*

O.A.C. 21 (C.I. 1470) is taken as the standard of comparison in table 35. In the 5-year average of tests at Beaverlodge, Alberta, it ranks sixth in yield. The single yield of Binder in 1931 probably shows this variety in too favorable a light, due to harvesting conditions.

O.A.C. 21 is recommended as an early malting barley; Eureka (beardless and hull-less) and Trebi as feed barleys; and Hannchen (C.I. 4841) as a dual-purpose barley where earliness is not at a premium. They should be seeded as early in the spring as the ground can be put in condition and wheat seeding disposed of. This is usually from the last of April to the middle of May. The best rate is 6 or 7 pecks per acre.

EXPERIMENTAL STATION, FORT VERMILION

ROBERT JONES, *Superintendent*

During the 5 years, 1927–31, eight varieties of barley have been tested in each of the years (table 35). Manchurian (C.A. no. 726) produced the highest yields. Fewer varieties have been tested at Fort Vermilion than at the other Alberta stations, so direct comparisons are not as readily made. However, Hannchen (C.I. 531), which was tested in 1929, 1930, and 1931, produced high yields and for the short period exceeded Manchurian. Hannchen and O.A.C. 21 (C.I. 1470) are recommended for growing. They should be seeded in early May at the rate of 2 bushels per acre.

UNIVERSITY OF ALBERTA, EDMONTON

O. S. AAMODT, *Department of Field Crops*

The highest yielding variety at Edmonton, Alberta, was an unnamed smooth-awned hybrid selection designated as 265×O.A.C. 21 (H–19–146). For the full 5-year period (table 35) its yield was 136.6 percent of that of O.A.C. 21 (C.I. 1470). The yield of Trebi was also very high. Hannchen (C.I. 531), with an average yield of several bushels lower than that of Trebi, followed it in order of yield. However, owing to its weak straw, Hannchen is not recommended for Alberta, except in the dry area in the southeastern part of the Province. Canadian Thorpe is the recommended two-rowed variety for central-northern Alberta. Trebi and O.A.C. 21 are the recommended six-rowed varieties for the whole Province. They should be seeded in late April at the rate of 6 to 8 pecks per acre.

BRITISH COLUMBIA

EXPERIMENTAL FARM, AGASSIZ

W. H. HICKS, *Superintendent*

Eight varieties were grown at Agassiz, British Columbia, for the 4 years reported in table 36. The yields of O.A.C. 21 and Bearer were about equal, with the latter slightly better. Trebi was the best of the varieties grown for less than 4 years. O.A.C. 21 is recommended. Seeding should be done in April at the rate of 2 bushels per acre.

EXPERIMENTAL STATION, SYDNEY (SAANICHTON)

E. M. STRAIGHT, *Superintendent*

Only two varieties were grown for the full 5-year period at Sydney (table 36). For the years in which they were grown, Charlottetown 80 and Trebi exceeded Gold in yield. Trebi and Charlottetown 80 are recommended. They should be seeded in April at the rate of 8 pecks per acre.

TABLE 36.—*Acre yields of varieties of barley grown at the experimental farm at Agassiz, British Columbia, and at the experimental station at Sydney (Saanichton), for 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Dominion Experimental Farms]

Station and variety	C.I. no.	Canadian accession no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Agassiz:															
Bearer (Ottawa 475)	4707	704	---	------	4	37.2	4	68.1	4	65.4	4	36.5	51.8	4	102.0
Charlottetown 80	2732	817	---	------	4	29.0	4	57.5	4	49.6	4	35.8	43.0	4	84.6
Early Chevalier (Ottawa 51)	2725	821	---	------	4	29.5	4	51.7	4	43.5	4	35.8	40.1	4	79.0
Gold	1145	829	---	------	4	27.6	4	58.1	4	53.8	4	35.2	43.7	4	86.0
Himalayan (Ottawa 59)	4838	765	---	------	4	27.1	4	54.1	4	47.7	4	28.8	39.4	4	77.6
Mensury (Chinese Ottawa 60)	4696	730	---	------	4	27.0	4	50.8	4	56.3	4	31.9	41.5	4	81.7
O.A.C. 21 [1]	1470	734	---	------	4	33.4	4	62.4	4	67.5	4	39.8	50.8	4	100.0
Success	4840	783	---	------	4	32.1	4	48.5	4	54.0	4	27.7	40.6	4	79.9
Plumage Archer	5033	806	---	------	---	------	4	56.2	4	41.6	4	27.9	------	3	74.1
Star	1701	748	---	------	---	------	4	77.0	4	69.8	4	31.3	------	3	104.9
Trebi	936	753	---	------	---	------	4	74.8	4	69.6	4	38.3	------	3	107.7
Velvet	4252	755	---	------	---	------	---	------	4	73.3	4	31.5	------	2	97.7
Sans Barb No. 3	5970	746	---	------	---	------	---	------	---	------	4	24.0	------	1	60.3
Sydney:															
Bearer (Ottawa 475)	4707	704	4	65.6	4	47.2	4	69.4	4	17.4	4	34.8	46.9	5	86.4
Gold [1]	1145	829	4	62.0	4	56.1	4	70.0	4	33.6	4	49.7	54.3	5	100.0
Charlottetown 80	2732	817	---	------	---	------	4	97.6	4	36.7	4	35.9	------	3	111.0
Hannchen	531	837	---	------	---	------	---	------	4	24.8	4	47.5	------	2	86.8
O.A.C. 21	1470	734	---	------	---	------	---	------	4	32.3	4	33.2	------	2	78.6
Plumage Archer	5033	806	---	------	---	------	---	------	4	30.7	4	38.5	------	2	83.1
Star	1701	748	---	------	---	------	---	------	4	31.7	4	45.4	------	2	92.6
Trebi	936	753	---	------	---	------	---	------	4	34.3	4	63.2	------	2	117.0
Sans Barb No. 3	5970	746	---	------	---	------	---	------	---	------	4	32.9	------	1	66.2

[1] Standard variety with which others are compared.

MANITOBA

EXPERIMENTAL FARM, BRANDON

M. J. TINLINE, *Superintendent*

O.A.C. 21 was used as the standard of comparison in table 37. Trebi has given good results in Manitoba and is recommended as a feed barley. However, where there is a demand for a variety suitable for malting O.A.C. 21 is recommended.

Barley should be seeded in April or early May in southern Manitoba and during May farther north. Seeding at a rate of 2 bushels per acre is recommended.

EXPERIMENTAL STATION, MORDEN

W. R. LESLIE, *Superintendent*

When measured by average yield, using O.A.C. 21 as a standard, Trebi stood in a class by itself. For the 4 years reported from

Morden in table 37, its yield was almost 7 bushels greater than its nearest competitor.

Trebi is recommended as a feed barley for seeding on summer-fallow in the Morden area. Mensury, O.A.C. 21, and Regal are recommended varieties.

Barley should be seeded by late April or early May at the rate of 8 pecks per acre.

TABLE 37.—*Acre yields of varieties of barley grown at the experimental farm at Brandon, Manitoba, and at the experimental station at Morden, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Dominion Experimental Farms]

Station and variety	C.I. no.	Canadian accession no.	Number of plots and acre yield												Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931		Average yield, 1927–31			
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield			Years	Yield
Brandon:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*			*Pct.*
Bearer (Ottawa 475)	4707	704	4	83.3	4	79.3	4	42.1	4	41.0	4	45.3	58.2		5	102.1
Canadian Thorpe	740	816	4	73.9	4	84.7	4	37.2	4	53.2	4	50.9	60.0		5	105.3
Duckbill (Ottawa 57)	1916	826	4	55.9	4	50.5	4	23.2	4	40.5	4	35.6	41.1		5	72.2
Hannchen	531	837	4	78.6	4	53.4	4	48.4	4	45.6	4	43.4	53.9		5	94.6
Himalayan (Ottawa 59)	4838	765	4	73.0	4	34.0	4	47.8	4	54.7	4	29.1	47.7		5	83.7
Mensury (Ottawa 60)	4696	730	4	83.5	4	49.2	4	57.2	4	79.1					4	109.4
O.A.C. 21 [1]	1470	734	4	79.5	4	39.1	4	47.8	4	79.5	4	39.0	57.0		5	100.0
Plumage Archer	5033	806	4	63.9	4	38.6	4	34.8	4	27.6	4	37.7	40.5		5	71.1
Star	1701	748	4	96.0	4	56.7	4	57.2	4	70.3	4	32.2	62.5		5	109.7
Trebi	936	753	4	87.3	4	51.0	4	49.6	4	67.1	4	43.3	59.7		5	104.7
Velvet	4252	755	4	95.6	4	66.1	4	43.5	4	62.4	4	37.7	61.1		5	107.2
Sol (Sixty-Day)	5031	782			4	37.6	4	48.5	4	44.8	4	34.5			4	80.5
Colsess	2792	772					4	48.6	4	55.8	4	31.4			3	81.7
Regal	5030	742					4	56.8	4	69.8	4	27.6			3	92.7
Binder	4703	810							4	51.5	4	36.5			2	74.3
Gordon (Ottawa 55)	4842	833							4	55.9	4	38.9			2	80.0
Morden:																
Bearer (Ottawa 475)	4707	704	4	60.8	4	46.0	4	48.6	4	50.8			51.6		4	87.0
Canadian Thorpe	740	816	4	52.0	4	35.4	4	47.1	4	42.9			44.4		4	74.9
Charlottetown 80	2732	817	4	59.3	4	41.2	4	57.8	4	43.8			50.5		4	85.3
Duckbill (Ottawa 57)	1916	826	4	40.2	4	35.4	4	45.5	4	48.9			42.5		4	71.8
Gold	1145	829	4	65.9	4	26.5	4	61.0	4	54.5			52.0		4	87.8
Hannchen	531	837	4	80.3	4	42.4	4	68.1	4	55.2			61.5		4	103.8
Manchurian (Ottawa 50)	4832	726	4	60.8	4	53.7	4	46.1	4	67.2			57.0		4	96.2
Mensury (Ottawa 60)	4696	730	4	70.7	4	48.3	4	49.9	4	83.8			63.2		4	106.7
O.A.C. 21 [1]	1470	734	4	78.5	4	44.8	4	42.5	4	71.1			59.2		4	100.0
Pearl	4834	780	4	39.4	4	13.4	4	40.7	4	28.5			30.5		4	51.5
Star	1701	748	4	63.4	4	53.0	4	42.1	4	55.4			53.5		4	90.3
Trebi	936	753	4	67.8	4	61.3	4	60.4	4	91.6			70.3		4	118.7
Velvet	4252	755	4	70.7	4	48.9	4	50.1	4	80.0			62.4		4	105.4
Colsess	2792	772							4	74.7					1	105.1
Early Chevalier (Ottawa 51)	2725	821							4	67.9					1	95.5
Glabron	4577	718							4	59.4					1	83.5
Gordon (Ottawa 55)	4842	833							4	62.0					1	87.2
Plumage Archer	5033	806							4	34.0					1	47.8
Regal	5030	742							4	78.5					1	110.4

[1] Standard variety with which others are compared.

NEW BRUNSWICK

EXPERIMENTAL STATION, FREDERICTON, NEW BRUNSWICK

C. F. BAILEY, *Superintendent*

The highest yield of the varieties grown at Fredericton, New Brunswick, in all 5 years was secured from O.A.C. 21. Bearer, Velvet, and Charlottetown 80 were almost as good. As may be seen in table 38, Trebi, which was grown only 4 years, gave good results in those years. Charlottetown 80 and O.A.C. 21 are recommended as suitable varieties for growing.

Barley should be seeded in May at the rate of 2 bushels per acre.

TABLE 38.—*Acre yields of varieties of barley grown at the experimental station at Fredericton, New Brunswick, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Dominion Experimental Farms]

Station and variety	C.I. no.	Canadian accession no.	Number of plots and acre yield												Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931		Average yield, 1927–31			
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield			Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*			*Pct.*
Bearer (Ottawa 475)	4707	704	4	50.2	4	33.0	4	54.0	4	46.2	4	45.8	45.8		5	97.9
Charlottetown 80	2732	817	4	43.3	4	33.6	4	53.1	4	45.0	4	48.0	44.6		5	95.2
Duckbill (Ottawa 57)	1916	826	4	32.7	4	44.9	4	53.6	4	29.3	4	25.5	37.2		5	79.4
Duckbill (M.C. 207)	4864	827	4	31.7	4	27.3	4	43.4	4	26.9	4	20.8	30.0		5	64.1
Early Chevalier (Ottawa 51)	2725	821	4	47.0	4	46.4	4	47.0	4	38.7	4	45.6	44.9		5	95.9
French Chevalier	175	822	4	41.0	4	29.7	4	45.4	4	38.4	4	39.0	38.7		5	82.6
Glabron	4577	718	4	54.9	4	26.8	4	46.4	4	41.5	4	35.2	41.0		5	87.4
Gold	1145	829	4	41.1	4	25.8	4	52.6	4	43.1	4	46.2	41.8		5	89.2
Guy Mayle (M.C. 312)	4839	764	4	44.0	4	19.3	4	40.9	4	31.9	4	30.7	33.4		5	71.2
Hannchen	531	837	4	49.5	4	21.3	4	54.3	4	36.5	4	42.1	40.7		5	87.0
Himalayan (Ottawa 59)	4838	765	4	43.0	4	19.3	4	38.1	4	35.1	4	33.8	33.9		5	72.3
Manchurian (Ottawa 50)	4832	726	4	50.7	4	30.2	4	53.8	4	32.4	4	28.0	39.0		5	83.3
Manchurian (C.R.)	4833	725	4	55.1	4	37.8	4	55.7	4	35.6	4	32.8	43.4		5	92.7
Mensury (Chinese Ottawa 60)	4696	730	4	55.9	4	39.1	4	50.8	4	41.8	4	36.0	44.7		5	95.5
O.A.C. 21 [1]	1470	734	4	56.2	4	37.5	4	53.9	4	45.1	4	41.5	46.8		5	100.0
Star	1701	748	4	49.9	4	29.4	4	52.8	4	37.8	4	49.1	43.8		5	93.5
Velvet	4252	755	4	59.4	4	34.6	4	52.4	4	43.2	4	38.0	45.5		5	97.2
Trebi	936	753	---	------	4	43.6	4	67.9	4	57.1	4	53.8	------		4	124.9
Plumage Archer	5033	806	---	------	---	------	4	36.0	4	30.8	4	27.0	------		3	66.8
Albert (Ottawa 54)	4852	701	---	------	---	------	---	------	4	33.3	4	35.9	------		2	79.9
Binder	4703	810	---	------	---	------	---	------	4	53.1	4	44.4	------		2	112.6
Canadian Thorpe	740	816	---	------	---	------	---	------	4	36.5	4	28.7	------		2	75.3
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	4	37.1	4	39.2	------		2	88.1
Horn	926	838	---	------	---	------	---	------	4	46.4	4	42.0	------		2	102.1
Monck	5971	847	---	------	---	------	---	------	4	22.2	4	34.1	------		2	65.0
Pontiac	4849	741	---	------	---	------	---	------	4	44.1	4	35.7	------		2	92.1
Stella (Ottawa 58)	4851	750	---	------	---	------	---	------	4	35.1	4	27.6	------		2	72.4

[1] Standard variety with which others are compared.

NOVA SCOTIA

EXPERIMENTAL FARM, NAPPAN

W. W. BAIRD, *Superintendent*

At Nappan, Nova Scotia, 16 varieties of barley were tested in all of the 5 years reported in table 39. Of those tested for the full period, the highest yields were secured for Manchurian (C.A. no. 725) and Charlottetown 80. Trebi, which was grown only in 4 years, gave high yields. A number of varieties grown for 2 years showed promise. Considering the high yields previously secured from Charlottetown 80, it is recommended for growing unless a six-rowed variety is required, in which case O.A.C. 21 should be used. Barley should be seeded May 1 to June 1 at the rate of 8 to 10 pecks per acre.

TABLE 39.—*Acre yields of varieties of barley grown at the experimental farm at Nappan, Nova Scotia, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Dominion Experimental Farms]

Variety	C.I. no.	Canadian accession no.	Number of plots and acre yield										Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931			
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Average yield, 1927–31	Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Albert (Ottawa 54)	4852	701	4	25.8	4	40.6	4	39.5	4	53.9	4	31.6	38.3	5	73.1
Bearer (Ottawa 475)	4707	704	4	46.0	4	55.1	4	53.9	4	52.2	4	36.7	48.8	5	93.1
Charlottetown 80	2732	817	4	42.0	4	66.7	4	63.5	4	55.5	4	39.4	53.4	5	102.0
Duckbill (Ottawa 57)	1916	826	4	11.6	4	33.8	4	49.7	4	41.5	4	26.7	32.7	5	62.4
Duckbill (M.C. 207)	4864	827	4	12.1	4	41.3	4	52.4	4	44.4	4	27.5	35.5	5	67.9
Early Chevalier (Ottawa 51)	2725	821	4	33.1	4	53.8	4	60.2	4	43.1	4	32.4	44.5	5	85.0
French Chevalier	175	822	4	33.8	4	53.9	4	51.7	4	50.9	4	35.7	45.2	5	86.3
Gold	1145	829	4	33.4	4	53.3	4	68.2	4	50.9	4	38.0	48.8	5	93.1
Guy Mayle (M.C. 312)	4839	764	4	31.0	4	60.8	4	54.1	4	52.9	4	38.9	47.5	5	90.8
Hannchen	531	837	4	36.2	4	52.0	4	63.0	4	58.0	4	41.6	50.2	5	95.8
Himalayan (Ottawa 59)	4838	765	4	31.9	4	60.2	4	51.8	4	49.5	4	34.6	45.6	5	87.1
Manchurian (Ottawa 50)	4832	726	4	43.3	4	65.1	4	58.0	4	52.5	4	38.3	51.4	5	98.2
Manchurian (C.R.)	4833	725	4	45.4	4	68.3	4	60.9	4	55.0	4	41.5	54.2	5	103.5
Mensury (Chinese Ottawa 60)	4696	730	4	36.7	4	59.2	4	64.6	4	48.6	4	35.3	48.9	5	93.3
O.A.C. 21[1]	1470	734	4	42.5	4	62.1	4	66.6	4	52.4	4	38.3	52.4	5	100.0
Star	1701	748	4	41.6	4	68.9	4	56.5	4	37.0	4	37.4	48.3	5	92.2
Trebi	936	753	---	------	4	81.5	4	73.2	4	67.3	4	48.3	------	4	123.2
Binder	4703	810	---	------	---	------	---	------	4	68.4	4	45.8	------	2	125.9
Canadian Thorpe	740	816	---	------	---	------	---	------	4	45.9	4	28.3	------	2	81.8
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	4	54.6	4	34.6	------	2	98.3
Horn	926	838	---	------	---	------	---	------	4	54.0	4	43.2	------	2	107.2
Plumage Archer	5033	806	---	------	---	------	---	------	4	41.1	4	26.5	------	2	74.5
Pontiac	4849	741	---	------	---	------	---	------	4	62.6	4	42.9	------	2	116.3
Stella (Ottawa 58)	4851	750	---	------	---	------	---	------	4	64.4	4	38.3	------	2	113.2
Velvet	4252	755	---	------	---	------	---	------	4	59.8	4	35.8	------	2	105.4
Glabron	4577	718	---	------	---	------	---	------	---	------	4	32.0	------	1	83.6
Spartan	5027	860	---	------	---	------	---	------	---	------	4	34.6	------	1	90.3

[1] Standard variety with which others are compared.

ONTARIO

CENTRAL EXPERIMENTAL FARM, OTTAWA

For the past 5 years, the results of which are reported in table 40, barleys of the Manchuria type have been the most productive at Ottawa. Manchurian (C.A. no. 726), Manchurian (C.A. no. 725), O.A.C. 21 (C.I. 1470), and Mensury all produced high yields. The highest average, however, was secured from Early Chevalier. Velvet was the most promising of the smooth-awned barleys. O.A.C. 21 and Mensury are recommended. They should be seeded in May at the rate of 2 bushels per acre.

EXPERIMENTAL STATION, KAPUSKASING

S. BALLANTYNE, *Superintendent*

O.A.C. 21 (C.I. 1470) was used as the standard of comparison for varieties at Kapuskasing, reported in table 40. Trebi produced higher yields than Hannchen in 3 of the 4 years in which Trebi was grown. In this part of Ontario early maturing varieties are essential, hence O.A.C. 21 is the recommended variety at present.

Barley should be seeded in May at the rate of 2 bushels per acre.

TABLE 40.—*Acre yields of varieties of barley grown at the Central Experimental Farm, Ottawa, at the experimental station at Kapuskasing, and at the Ontario Agricultural College, Guelph, Ontario, in 1 or more of the years 1927–31*

[Data for Ottawa and Kapuskasing obtained through the courtesy of the Dominion Experimental Farms and for Guelph through the courtesy of the Ontario Agricultural College]

Station and variety	C.I. no.	Canadian accession no.	Number of plots and acre yield												Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931		Average yield, 1927–31			
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield			Years	Yield
Ottawa:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*			*Pct.*
Bearer (Ottawa 475)	4707	704	4	44.5	4	42.9	4	27.1	4	31.8	4	26.2	34.5		5	81.5
Charlottetown 80	2732	817	4	38.4	4	40.2	4	27.3	4	38.3	4	27.9	34.4		5	81.3
Clifford	4845	825	4	42.9	4	37.3	4	28.0	4	39.7	4	37.4	37.1		5	87.6
Duckbill (Ottawa 57)	1916	826	4	23.5	4	19.9	4	13.7	4	16.0	4	9.5	16.5		5	39.0
Duckbill (M.C. 207)	4864	827	4	20.1	4	31.9	4	20.4	---	------	---	------	------		3	56.8
Early Chevalier (Ottawa 51)	2725	821	4	46.9	4	35.8	4	35.6	4	49.8	4	46.7	43.0		5	101.5
Escourgeon	2716	714	4	56.2	4	41.5	4	27.3	4	40.2	4	33.6	39.8		5	94.0
Gold	1145	829	4	50.6	4	27.9	4	25.2	4	34.2	4	18.7	31.3		5	74.0
Gordon (Ottawa 55)	4842	833	4	45.5	4	41.9	4	23.2	4	35.5	4	37.9	37.4		5	88.4
Hannchen	531	837	4	45.6	4	37.7	4	30.9	4	27.1	4	26.8	33.6		5	79.4
Manchurian (Ottawa 50)	4832	726	4	60.6	4	47.1	4	29.7	4	40.2	4	34.0	42.3		5	100.0
Manchurian (C.R.)	4833	725	4	62.5	4	48.6	4	30.0	4	39.3	4	32.1	42.5		5	100.4
Mensury (Ottawa 60)	4696	730	4	53.9	4	39.4	4	28.0	4	42.6	4	37.7	40.3		5	95.3
Nugent	4706	733	4	57.6	4	47.9	4	31.1	4	35.7	4	28.5	40.2		5	94.9
O.A.C. 21 [1]	1470	734	4	53.3	4	39.8	4	34.4	4	47.0	4	37.1	42.3		5	100.0
Star	1701	748	4	46.2	4	39.2	4	24.4	4	36.4	4	34.8	36.2		5	96.6
O.A.C. 21 (Saskatchewan 228)	4708	735	4	49.2	4	45.6	4	29.1	4	40.7	4	39.7	40.9		5	85.5
Stella (Ottawa 58)	4851	750	4	63.5	4	43.6	4	30.0	4	33.6	4	24.9	39.1		5	92.4
Velvet	4252	755	4	57.5	4	45.7	4	30.3	4	34.5	4	37.1	41.0		5	96.9
Glabron	4577	718	---	------	4	44.9	4	33.4	4	39.8	4	37.5	------		4	98.3
Trebi	936	753	---	------	4	46.8	4	31.9	4	41.1	4	39.2	------		4	100.4

[1] Standard variety with which others are compared.

TABLE 40.—*Acre yields of varieties of barley grown at the Central Experimental Farm, Ottawa, at the experimental station at Kapuskasing, and at the Ontario Agricultural College, Guelph, Ontario, in 1 or more of the years 1927–31*—Con.

Station and variety	C.I. no.	Canadian accession no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Ottawa—Continued.				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Colsess	2792	772	---	------	---	------	---	------	4	33.3	4	29.9	------	2	75.1
Comfort	4578	712	---	------	---	------	---	------	4	33.3	4	39.5	------	2	86.6
Featherston	1120	715	---	------	---	------	---	------	4	30.8	4	44.4	------	2	89.4
Monck	5971	847	---	------	---	------	---	------	4	28.9	4	26.4	------	2	65.8
Plumage Archer	5033	806	---	------	---	------	---	------	4	22.1	4	6.6	------	2	34.1
Pontiac	4849	741	---	------	---	------	---	------	4	40.5	4	38.9	------	2	94.4
Alpha	959	801	---	------	---	------	---	------	4	41.2	4	43.9	------	2	101.2
Kapuskasing:															
Albert (Ottawa 54)	4852	701	4	43.7	4	39.7	4	20.6	4	35.4	4	26.9	33.3	5	78.7
Bearer (Ottawa 475)	4707	704	4	58.1	4	44.1	4	33.2	4	58.6	4	37.8	46.4	5	109.6
Binder	4703	810	4	68.3	4	48.7	4	47.3	4	64.0	4	43.0	54.3	5	128.3
Charlottetown 80	2732	817	4	51.4	4	38.5	4	31.1	4	55.5	4	33.5	42.0	5	99.3
Duckbill (Ottawa 57)	1916	826	4	59.2	4	38.8	4	29.8	4	42.0	4	29.3	39.8	5	94.2
Duckbill (M.C. 207)	4864	827	4	63.3	4	47.0	4	30.7	4	55.3	4	36.7	46.6	5	110.2
Early Chevalier (Ottawa 51)	2725	821	4	48.5	4	36.6	4	36.4	4	46.5	4	32.3	40.1	5	94.7
French Chevalier	175	822	4	62.6	4	43.3	4	25.8	4	44.4	4	32.4	41.7	5	98.6
Gold	1145	829	4	54.8	4	42.5	4	36.3	4	60.4	4	37.6	46.3	5	109.6
Guy Mayle (M.C. 312)	4839	764	4	44.5	4	52.1	4	36.0	4	63.7	4	32.1	45.7	5	108.0
Hannchen	521	837	4	63.9	4	51.6	4	35.1	4	58.3	4	45.9	51.0	5	120.5
Himalayan (Ottawa 59)	4838	765	4	46.5	4	46.0	4	35.3	4	42.2	4	31.8	40.4	5	95.5
Manchurian (Ottawa 50)	4832	726	4	60.9	4	43.7	4	35.4	4	47.9	4	38.0	45.2	5	106.9
Manchurian (C.R.)	4833	725	4	61.8	4	43.8	4	28.9	4	54.5	4	39.9	45.8	5	108.3
Mensury (Ottawa 60)	4696	730	4	53.3	4	34.0	4	32.9	4	53.5	4	41.1	43.0	5	101.6
O.A.C. 21 [1]	1470	734	4	50.0	4	37.9	4	33.5	4	51.4	4	38.6	42.3	5	100.0
Pontiac	4849	741	4	63.4	4	42.0	4	33.4	4	58.3	4	37.4	46.9	5	110.9
Star	1701	748	4	58.0	4	41.5	4	37.9	4	53.6	4	34.4	45.1	5	106.6
Velvet	4252	755	4	34.8	4	26.9	4	26.2	4	49.0	4	35.7	34.5	5	81.6
Trebi	936	753	---	------	4	51.0	4	36.7	4	63.8	4	48.6	------	4	124.0
Plumage Archer	5033	806	---	------	---	------	4	33.0	4	54.5	4	25.7	------	3	91.7
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	4	44.3	4	32.7	------	2	85.6
Guelph:															
Velvet	4252	755	3	60.6	3	43.6	3	38.8	3	56.5	3	67.8	53.5	5	106.8
Bearer	4707	704	3	59.2	3	48.3	3	37.1	3	58.9	3	58.2	52.3	5	104.6
Oderbrucker	2700	1059	3	50.9	3	35.9	3	38.5	3	61.5	3	68.0	51.0	5	101.8
Colsess	2792	772	3	49.5	3	47.0	3	38.1	3	60.2	3	57.0	50.4	5	100.6
O.A.C. 21 [1]	1470	734	3	53.2	3	48.8	3	37.7	3	51.8	3	58.7	50.0	5	100.0
Manchuria (Minnesota 184)	2330	724	3	54.0	3	43.3	3	42.1	3	49.5	3	57.3	49.2	5	98.4
Wisconsin Pedigree	------	757	3	50.3	3	34.4	3	43.6	3	56.9	3	59.7	49.0	5	97.9
Mensury (Ottawa 60)	4696	730	3	58.7	3	48.8	3	28.3	3	52.1	3	56.1	48.8	5	97.5
Mandscheuri 620	------	1091	3	53.8	3	34.3	3	38.3	3	51.5	3	50.1	45.6	5	91.1
Mandscheuri (Manchuria)	244	794	3	52.4	3	32.0	3	32.9	3	48.6	3	48.5	42.9	5	85.7
Common Six-Row	184	1060	3	42.3	3	30.0	3	33.1	3	46.0	3	53.8	41.0	5	82.0
Success	2707	1062	3	37.6	3	23.6	3	34.8	3	50.1	3	55.0	40.2	5	80.4
French Chevalier	175	822	3	48.8	3	50.6	3	32.9	3	58.6	3	60.5	50.3	5	100.5
Garton's Spratt-Archer	5989	803	3	56.6	3	37.3	3	39.3	3	59.7	3	53.9	49.4	5	98.6
Charlottetown 80	2732	817	3	36.0	3	40.9	3	49.7	3	52.1	3	57.4	47.2	5	94.4
Garton's Standwell	------	861	3	45.2	4	41.1	3	30.8	3	45.3	3	53.7	43.2	5	86.4
Garton's Triumph	------	796	3	46.4	3	41.3	3	21.4	3	45.3	3	53.6	41.6	5	83.1
Duckbill (Ottawa 57)	1916	826	3	38.4	3	27.8	3	24.7	3	52.7	3	55.7	39.9	5	79.7
Duckbill	------	1063	3	34.5	3	27.6	3	27.0	3	49.9	3	58.6	39.5	5	79.0
Guy Mayle (Himalaya)	620	763	3	50.1	3	44.8	3	39.9	3	58.1	3	54.3	49.4	5	98.8
Purple (Black Hull-less)	4876	1066	3	45.9	3	48.2	3	33.6	3	51.5	3	56.3	47.1	5	94.1
Winnipeg No. 2	4877	1067	3	50.9	3	39.6	3	28.8	3	46.4	3	56.1	44.4	5	88.6
Black Hull-less	556	1065	3	45.6	3	42.8	3	31.7	3	45.3	3	57.1	44.5	5	88.9
New White Hull-less (Nepal)	4878	1068	3	40.9	3	35.6	3	25.3	3	51.4	3	29.8	36.6	5	73.1

[1] Standard variety with which others are compared.

ONTARIO AGRICULTURAL COLLEGE, GUELPH

W. J. SQUIRREL, *Department of Field Husbandry*

The highest average yield at Guelph was secured from Velvet (table 40). The yield of Bearer was only 1 bushel less. Velvet produced 3.5 bushels more grain than did O.A.C. 21 (C.I. 1470). This latter variety, however, is still considered the conservative recommendation to farmers. Barley should be seeded in April at the rate of 2 bushels per acre.

PRINCE EDWARD ISLAND

EXPERIMENTAL STATION, CHARLOTTETOWN

J. A. CLARK, *Superintendent*

The yields from Charlottetown, Prince Edward Island, reported in table 41, are in accord with those of previous years. Charlottetown 80 has always been a good variety here, and it is the only one that exceeded O.A.C. 21 for the 5-year period. It is recommended for this Province. Barley should be seeded in May at the rate of 2 bushels per acre.

TABLE 41.—*Acre yields of varieties of barley grown at the experimental station at Charlottetown, Prince Edward Island, in 1 or more of the years 1927–31*

[Data obtained through the courtesy of the Dominion Experimental Farms]

Variety	C.I. no.	Canadian accession no.	Number of plots and acre yield										Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931		Average yield, 1927–31		
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Bearer (Ottawa 475)	4707	704	4	28.9	4	32.0	4	48.3	4	42.3	4	23.6	35.0	5	94.5
Charlottetown 80	2732	817	4	28.3	4	39.5	4	53.9	4	39.2	4	37.0	39.6	5	106.9
Duckbill (Ottawa 57)	1916	826	4	9.3	4	32.9	4	39.1	4	24.5	4	19.7	25.1	5	67.8
Early Chevalier (Ottawa 51)	2725	821	4	29.0	4	36.3	4	45.7	4	35.1	4	22.7	33.8	5	91.1
French Chevalier	175	822	4	22.4	4	36.8	4	47.9	4	31.0	4	20.4	31.7	5	85.6
Gold	1145	829	4	15.6	4	44.5	4	43.4	4	35.9	4	27.4	33.4	5	90.1
Guy Mayle (M.C. 312)	4839	764	4	12.5	4	22.7	4	40.3	4	22.8	4	16.2	22.9	5	61.8
Hannchen	531	837	4	27.0	4	34.5	4	48.7	4	34.2	4	20.2	32.9	5	88.9
Himalayan (Ottawa 59)	4838	765	4	11.7	4	18.5	4	39.8	4	21.8	4	14.5	21.3	5	57.4
Horn	926	838	4	28.2	4	33.8	4	44.0	4	36.0	4	26.0	33.6	5	90.7
Manchurian (Ottawa 50)	4832	726	4	24.7	4	41.2	4	48.7	4	29.2	4	20.0	32.8	5	88.4
Manchurian (C.R. 14)	4833	725	4	36.5	4	43.9	4	49.0	4	32.1	4	21.5	36.6	5	98.8
Mensury (Chinese Ottawa 60)	4696	730	4	25.3	4	35.2	4	44.5	4	34.0	4	19.4	31.7	5	85.5
O.A.C. 21 [1]	1470	734	4	33.0	4	45.5	4	47.7	4	35.1	4	23.9	37.0	5	100.0
Star	1701	748	4	28.6	4	32.2	4	47.3	4	33.0	4	27.0	33.6	5	90.8
Velvet	4252	755	4	32.1	4	43.6	4	49.9	4	32.0	4	27.0	36.9	5	99.7
Binder	4703	810	---	------	---	------	---	------	4	37.4	4	23.9	------	2	103.9
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	4	31.8	4	23.2	------	2	93.2
Pontiac	4849	741	---	------	---	------	---	------	4	31.0	4	13.3	------	2	75.1
Stella (Ottawa 58)	4851	750	---	------	---	------	---	------	4	29.6	4	15.5	------	2	76.4
Trebi	936	753	---	------	---	------	---	------	4	31.7	4	21.3	------	2	89.8

[1] Standard variety with which others are compared.

QUEBEC

EXPERIMENTAL STATION, CAP ROUGE

GUS A. LANGELIER, *Superintendent*

At Cap Rouge, Quebec, 10 varieties were grown in all of the 5 years reported in table 42. Of these, Bearer, produced the highest yield. Mensury, Charlottetown 80, and O.A.C. 21 followed in the order named. Of the varieties grown less than 5 years, Trebi and Binder made the best showing. Mensury is recommended. Barley should be seeded in May at the rate of 2 bushels per acre.

EXPERIMENTAL STATION, LENNOXVILLE

J. A. MCCLARY, *Superintendent*

Results at Lennoxville for only 4 years are reported in table 42. Charlottetown 80, Manchurian (C.A. no. 725), Mensury, and O.A.C. 21 were the four best varieties. Charlottetown 80, Mensury, or O.A.C. 21 are recommended. They should be seeded early in May at the rate of 2 bushels per acre.

TABLE 42.—*Acre yields of varieties of barley grown at the experimental stations at Cap Rouge, Lennoxville, Ste. Anne de la Pocatiere, and at MacDonald College, Ste. Anne de Bellevue, Quebec, in 1 or more of the years 1927–31*

[Data for Cap Rouge, Lennoxville, and Ste. Anne de la Pocatiere obtained through the courtesy of the Dominion Experimental Farms and for MacDonald College through the courtesy of MacDonald College]

Station and variety	C.I. no.	Canadian accession no.	Number of plots and acre yield												Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931		Average yield, 1927–31			
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield			Years	Yield
Cap Rouge:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*			*Pct.*
Bearer (Ottawa 475)	4707	704	4	29.4	4	35.3	4	31.2	4	61.5	4	52.4	42.0		5	111.4
Charlottetown 80	2732	817	4	28.4	4	31.1	4	26.1	4	54.6	4	50.0	38.0		5	101.0
Duckbill (Ottawa 57)	1916	826	4	18.6	4	21.0	---	---	4	38.1	4	30.9	---		4	66.6
Duckbill (M.C. 207)	4864	827	4	22.2	4	26.9	4	17.3	4	36.3	4	37.2	28.0		5	74.3
Early Chevalier (Ottawa 51)	2725	821	4	26.3	4	29.0	4	23.3	4	52.4	4	47.9	35.8		5	95.0
Hannchen	531	837	4	26.3	4	31.0	4	19.6	4	43.8	4	47.8	33.7		5	89.4
Himalayan (Ottawa 59)	4838	765	4	23.8	4	28.3	4	25.5	4	48.2	4	40.0	33.2		5	88.0
Manchurian (C.R. 14)	4833	725	4	24.4	4	36.1	4	25.3	4	48.7	4	51.2	37.1		5	98.6
Mensury (Chinese Ottawa 60)	4696	730	4	28.1	4	34.7	4	27.9	4	47.3	4	56.0	38.8		5	103.0
O.A.C. 21 [1]	1470	734	4	26.7	4	32.7	4	25.3	4	52.7	5	51.0	37.7		5	100.0
Star	1701	748	4	22.5	4	34.5	4	25.5	4	50.1	4	46.1	35.7		5	94.9
Velvet	4252	755	4	28.3	---	---	---	---	4	45.9	4	54.8	---		3	98.9
Monck	5971	847	---	---	4	31.8	4	19.6	4	46.5	4	42.9	---		4	87.1
Pontiac	4849	741	---	---	4	36.7	4	26.1	4	55.9	4	47.0	---		4	102.5
Plumage Archer	5033	806	---	---	---	---	4	26.5	4	36.0	4	40.7	---		3	80.0
Alpha	959	801	---	---	---	---	---	---	4	56.9	4	53.6	---		2	106.6
Binder	4703	810	---	---	---	---	---	---	4	63.1	4	54.3	---		2	113.2
Canadian Thorpe	740	816	---	---	---	---	---	---	4	37.8	4	41.0	---		2	76.8
French Chevalier	175	822	---	---	---	---	---	---	4	40.7	4	34.9	---		2	72.0
Gordon (Ottawa 55)	4842	833	---	---	---	---	---	---	4	43.1	4	42.3	---			82.9
Manchurian (Ottawa 50)	4832	726	---	---	---	---	---	---	4	54.9	4	46.4	---		2	97.4
Stella (Ottawa 58)	4851	750	---	---	---	---	---	---	4	51.1	4	46.1	---		2	93.7
Trebi	936	753	---	---	---	---	---	---	4	68.3	4	59.6	---		2	123.7

[1] Standard variety with which others are compared.

TABLE 42.—*Acre yields of varieties of barley grown at the experimental stations at Cap Rouge, Lennoxville, Ste. Anne de la Pocatiere, and at MacDonald College, Ste. Anne de Bellevue, Quebec, in 1 or more of the years 1927–31*—Continued

Station and variety	C. I. no.	Canadian accession no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Years	Yield
Lennoxville:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Bearer (Ottawa 475)	4707	704	4	55.4	---	------	4	52.5	4	68.3	4	61.5	59.4	4	92.6
Charlottetown 80	2732	817	4	63.2	---	------	4	73.0	4	71.8	4	59.6	66.9	4	104.2
Duckbill (Ottawa 57)	1916	826	4	50.7	---	------	4	32.2	4	44.2	4	41.9	42.3	4	65.8
Early Chevalier (Ottawa 51)	2725	821	4	65.6	---	------	4	65.7	4	69.7	4	55.2	64.1	4	99.8
French Chevalier	175	822	4	59.8	---	------	4	46.8	4	64.2	4	52.9	55.9	4	87.1
Gold	1145	829	4	56.5	---	------	4	79.0	4	60.7	4	52.5	62.2	4	96.9
Hannchen	531	837	4	66.1	---	------	4	68.2	4	43.4	4	47.7	56.4	4	87.8
Himalayan (Ottawa 59)	4838	765	4	59.0	---	------	4	73.3	4	34.4	4	31.5	49.6	4	77.2
Manchurian (Ottawa 50)	4832	726	4	72.7	---	------	4	53.7	4	69.5	4	53.5	62.4	4	97.2
Manchurian (C.R. 14)	4833	725	4	67.8	---	------	4	56.4	4	69.9	4	71.0	66.3	4	103.3
Mensury (Chinese Ottawa 60)	4696	730	4	64.4	---	------	4	69.3	4	62.6	4	68.6	66.2	4	103.2
O.A.C. 21 [1]	1470	734	4	60.5	---	------	4	75.9	4	58.2	4	62.1	64.2	4	100.0
Pontiac	4849	741	4	52.9	---	------	4	44.1	4	66.5	4	67.7	57.8	4	90.1
Plumage Archer	5033	806	---	------	---	------	4	44.7	4	32.8	4	44.2	------	3	62.0
Trebi	936	753	---	------	---	------	4	66.2	4	81.1	4	60.8	------	3	106.1
Alpha	959	801	---	------	---	------	---	------	4	88.8	4	60.4	------	2	124.0
Binder	4703	810	---	------	---	------	---	------	4	60.7	4	63.1	------	2	102.9
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	4	58.6	4	45.8	------	2	86.8
Monck	5971	847	---	------	---	------	---	------	4	51.2	4	56.0	------	2	89.1
Oxford (hull-less)	5974	740	---	------	---	------	---	------	4	40.9	4	42.1	------	2	69.0
Velvet	4252	755	---	------	---	------	---	------	4	65.2	4	59.8	------	2	103.9
Ste. Anne de la Pocatiere:															
Bearer (Ottawa 475)	4707	704	4	60.6	4	73.3	4	65.3	4	68.7	4	59.7	65.5	5	104.9
Charlottetown 80	2732	817	4	67.5	4	63.2	4	55.0	4	55.7	4	50.1	58.3	5	93.3
Duckbill (Ottawa 57)	1916	826	4	60.6	4	65.2	4	40.0	4	45.5	4	31.9	48.6	5	77.8
Duckbill (M.C. 207)	4864	827	4	65.2	4	68.2	4	51.0	4	48.2	4	38.5	54.2	5	86.8
Early Chevalier (Ottawa 51)	2725	821	4	47.8	4	57.5	4	60.0	4	53.5	4	47.3	53.2	5	85.2
French Chevalier	175	822	4	60.2	4	55.2	4	57.0	4	46.8	4	41.5	52.1	5	83.5
Gold	1145	829	4	66.6	4	62.9	4	60.0	4	57.6	4	44.5	58.3	5	93.3
Hannchen	531	837	4	74.5	4	64.3	4	72.0	4	64.1	4	47.2	64.4	5	103.1
Manchurian (Ottawa 50)	4832	726	4	74.9	4	68.2	4	55.0	4	59.1	4	53.0	62.0	5	99.3
Manchurian (C.R. 14)	4833	725	4	76.1	4	66.2	4	58.0	4	56.7	4	53.1	62.0	5	99.3
Mensury (Ottawa 60)	4696	730	4	62.6	4	66.9	4	57.0	---	------	4	53.7	------	4	94.5
O.A.C. 21 [1]	1470	734	4	75.5	4	55.7	4	74.0	4	58.2	4	49.0	62.5	5	100.0
Star	1701	748	4	64.6	4	61.3	4	63.0	4	69.3	4	65.1	64.7	5	103.5
Himalayan (Ottawa 59)	4838	765	4	62.3	4	56.0	---	------	4	52.6	4	46.0	------	4	91.0
Trebi	936	753	---	------	4	77.0	4	88.0	4	70.0	4	65.1	------	4	126.7
MacDonald College: [2]															
Six-rowed:															
O.A.C. 21 [1]	1470	734	6	59.8	---	------	6	43.3	6	57.5	4	55.7	------	4	100.0
Mensury (Ottawa 60)	4696	730	5	58.1	---	------	5	43.0	5	64.0	4	50.0	------	4	99.4
Star	1701	748	5	57.1	---	------	5	45.1	5	63.7	---	------	------	3	103.3
Bearer (Ottawa 475)	4707	704	5	64.9	---	------	5	50.0	5	62.3	4	46.1	------	4	103.2
Manchurian (C.R. 14)	4833	725	5	61.5	---	------	5	49.2	5	60.0	4	44.5	------	4	99.5
Pontiac (Mandscheuri, M.C. 909)	4849	741	---	------	---	------	5	52.3	5	60.8	4	50.5	------	3	104.5
Two-rowed:															
O.A.C. 21 [1]	1470	734	6	51.6	8	36.8	6	49.9	5	63.5	4	52.9	50.9	5	100.0
Hannchen	531	837	5	52.9	5	31.6	4	52.8	4	51.0	4	49.5	47.6	5	93.4
Charlottetown 80	2732	817	5	56.3	5	29.0	4	53.1	4	60.1	4	50.3	49.8	5	97.7
Monck	5971	847	---	------	5	32.3	4	47.3	4	56.2	4	49.5	------	4	91.2

[1] Standard variety with which others are compared.
[2] These results were obtained from 1/100-acre plots.

EXPERIMENTAL STATION, STE. ANNE DE LA POCATIERE

J. A. St. Marie, *Superintendent*

O.A.C. 21 is the standard variety used in table 42 and is also the recommended variety for the district surrounding Ste. Anne de la Pocatiere, Quebec. Hannchen is recommended where a two-rowed variety is preferred. Trebi shows great promise, having headed the list in the 4 years tested. However, its short straw does not recommend it for general use. The Manchuria-type barleys do well in this locality.

Barley should be seeded in May at the rate of 2 bushels per acre.

MACDONALD COLLEGE, STE. ANNE DE BELLEVUE

Emile A. Lods, *professor of agronomy*

Of the three varieties grown at Ste. Anne de Bellevue in all 5 of the years reported in table 42, O.A.C. 21 produced the highest yield. Only data applying to the older varieties are reported at this time. A large number of new varieties resulting from breeding work are being tested annually. Bearer and Pontiac were the best varieties grown for a shorter period. O.A.C. 21 and Bearer are recommended to the growers. If a 2-rowed sort is desired, either Hannchen or Charlottetown 80 should be satisfactory. Barley should be seeded as early as soil and weather conditions permit the preparation of the seed bed, and at the rate of 8 pecks per acre.

SASKATCHEWAN

EXPERIMENTAL FARM, INDIAN HEAD

W. H. Gibson, *Superintendent*

As is noted in table 43, the 1931 yields of certain varieties were not comparable at Indian Head. Since this affects a number of standard sorts, all varieties grown for the 4-year period 1927–30 should be considered. On the basis of this period, the highest-yielding varieties were Trebi, Gold, Bearer, and Colsess. Hannchen (C.I. 531) produced high yields for the period 1922–26. For this reason Hannchen and Trebi are recommended. Seeding should be done in May at the rate of 2 bushels per acre.

EXPERIMENTAL STATION, ROSTHERN

W. A. Munro, *Superintendent*

At Rosthern 16 varieties were grown in all of the 5 years reported in table 43. Of those grown for the full period, Trebi, Hannchen (C.I. 531), and Horn produced the highest yields and in the order named. These yields are in general agreement with earlier results at this station. Trebi and Hannchen are recommended. They should be seeded in May at the rate of 8 pecks per acre.

TABLE 43.—*Acre yields of varieties of barley grown at the experimental farm at Indian Head, at the experimental stations at Rosthern, Scott, and Swift Current, and at the University of Saskatchewan, Saskatoon, Saskatchewan, in 1 or more of the years 1927–31*

[Data for Indian Head, Rosthern, Scott, and Swift Current obtained through the courtesy of the Dominion Experimental Farms and for Saskatoon through the courtesy of the University of Saskatchewan]

Station and variety	C.I. no.	Canadian accession no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Year	Yield
Indian Head:				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Albert (Ottawa 54)	4852	701	4	41.7	4	37.5	4	45.0	4	16.9	2	[1] 05.9	------	4	68.5
Archer	5988	802	4	78.5	4	43.8	4	25.1	4	32.0	4	14.0	38.7	5	81.5
Bearer (Ottawa 475)	4707	704	4	116.9	4	58.9	4	43.5	4	31.9	2	[1] 32.7	------	4	121.9
Binder	4703	810	4	102.8	4	49.1	4	39.5	4	37.7	4	32.0	52.2	5	110.0
Canadian Thorpe	740	816	4	95.9	4	60.0	4	47.5	4	31.3	2	[1] 27.5	------	4	113.9
Charlottetown 80	2732	817	4	95.5	4	56.5	4	52.1	4	42.3	4	21.7	53.6	5	112.9
Duckbill (Ottawa 57)	1916	826	4	76.1	4	54.6	4	31.5	4	37.7	4	21.0	44.2	5	93.0
Early Chevalier (Ottawa 51)	2725	821	4	75.0	4	36.9	4	52.5	4	25.3	4	29.3	43.8	5	92.2
Gold	1145	829	4	94.3	4	68.7	4	53.6	4	49.8	2	[1] 38.9	------	4	129.3
Hannchen	531	837	4	91.3	4	52.9	4	52.2	4	37.5	4	43.3	55.4	5	116.8
Himalayan (Ottawa 59)	4838	765	4	43.0	4	41.5	4	51.5	4	34.9	4	27.9	39.8	5	83.7
O.A.C. 21 (Saskatchewan 228)	4708	735	4	71.7	4	39.3	4	53.8	4	34.6	4	23.0	44.5	5	93.7
Kinver Chevalier	587	823	4	64.8	4	38.1	4	30.4	4	31.8	4	13.2	35.7	5	75.1
Maltster	585	845	4	109.1	4	69.4	4	46.8	4	36.3	4	22.8	56.9	5	119.8
Mensury (Ottawa 60)	4696	730	4	69.0	4	50.6	4	53.5	4	29.6	2	[1] 32.1	------	4	98.4
O.A.C. 21 [2]	1470	734	4	69.4	4	50.6	4	56.3	4	29.7	4	31.4	47.5	5	100.0
Pearl	4834	780	4	68.6	4	43.0	4	44.4	4	30.4	4	26.0	42.5	5	89.5
Plumage Archer	5033	806	4	79.2	4	48.7	4	24.9	4	26.5	4	38.2	43.5	5	91.6
Spratt Archer	5989	803	4	101.0	4	46.8	4	36.8	4	31.0	2	[1] 17.0	------	4	104.7
Standwell	584	861	4	100.4	4	56.9	4	44.6	4	43.5	4	21.8	53.4	5	112.6
Star	1701	748	4	66.1	4	33.9	4	46.5	4	27.6	4	25.1	39.8	5	83.9
Stella (Ottawa 58)	4851	750	4	78.4	4	43.4	4	47.3	4	28.3	4	22.9	44.1	5	92.8
Velvet	4252	755	4	85.4	4	43.3	4	51.4	4	30.0	4	28.6	47.7	5	100.5
Colsess	2792	772	---	------	4	60.3	4	60.0	4	38.3	4	37.3	------	4	116.6
Trebi	936	753	---	------	4	75.6	4	66.6	4	53.1	4	34.8	------	4	137.0
Regal	5030	742	---	------	---	------	4	58.6	4	45.6	4	29.8	------	3	114.1
Glabron	4577	718	---	------	---	------	---	------	4	29.8	2	[1] 30.1	------	1	100.3
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	4	37.8	2	[1] 25.9	------	1	127.3
Manchurian (Ottawa 50)	4832	726	---	------	---	------	---	------	4	31.8	4	28.8	------	2	99.2
Sol (Sixty-Day)	5031	782	---	------	---	------	---	------	4	22.2	2	[1] 28.0	------	1	74.7
Sans Barb	5970	746	---	------	---	------	---	------	---	------	2	[1] 24.9	------	---	------
Rosthern:															
Albert (Ottawa 54)	4852	701	4	34.3	4	34.3	---	------	4	39.4	4	26.3	------	4	55.7
Bearer (Ottawa 475)	4707	704	4	62.0	4	62.6	4	50.8	4	45.6	4	61.9	56.6	5	95.6
Canadian Thorpe	740	816	4	50.8	4	63.2	4	57.3	4	50.2	4	70.0	58.3	5	98.5
Charlottetown 80	2732	817	4	67.9	4	56.1	4	57.9	4	55.6	4	64.0	60.3	5	101.9
Duckbill (Ottawa 57)	1916	826	4	36.6	4	37.2	4	44.9	4	39.0	4	57.3	43.0	5	72.7
Early Chevalier (Ottawa 51)	2725	821	4	53.2	4	53.2	4	53.2	4	46.7	4	51.7	51.6	5	87.2
Gold	1145	829	4	64.4	4	54.9	4	56.7	4	44.2	4	42.7	52.6	5	88.9
Hannchen	531	837	4	67.9	4	74.2	4	62.0	4	58.5	4	67.1	65.9	5	111.5
Himalayan (Ottawa 59)	4838	765	4	43.7	4	46.7	4	67.9	4	67.7	4	55.0	56.2	5	95.0
Horn	926	838	4	60.8	4	69.5	4	70.9	4	64.4	4	62.3	65.6	5	110.9
Manchurian (Ottawa 50)	4832	726	4	60.8	4	70.3	4	44.9	4	46.7	4	55.4	55.6	5	94.0
Mensury (Ottawa 60)	4696	730	4	56.7	4	75.6	4	50.2	4	53.1	4	67.9	60.7	5	102.6
O.A.C. 21 [2]	1470	734	4	61.4	4	69.1	4	54.9	4	51.0	4	59.4	59.2	5	100.0
O.A.C. 21 (Saskatchewan 228)	4708	735	4	57.3	4	76.2	4	53.7	4	54.6	4	66.6	61.7	5	104.3
Star	1701	748	4	56.7	4	60.2	4	47.2	4	53.5	4	66.6	56.8	5	96.1
Stella (Ottawa 58)	4851	750	4	60.2	4	63.8	---	------	4	53.3	4	61.9	------	4	99.3

[1] Yields unreliable; 2 seedings, therefore, not included in average.
[2] Standard variety with which others are compared.

TABLE 43.—*Acre yields of varieties of barley grown at the experimental farm at Indian Head, at the experimental stations at Rosthern, Scott, and Swift Current, and at the University of Saskatchewan, Saskatoon, Saskatchewan, in 1 or more of the years 1927–31*—Continued

Station and variety	C.I. no.	Canadian accession no.	Number of plots and acre yield										Average yield, 1927–31	Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931				
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield		Year	Yield
				Bu.		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*		*Pct.*
Rosthern—Continued.															
Trebi	936	753	4	68.5	4	70.0	4	63.2	4	69.2	4	60.2	66.2	5	111.9
Velvet	4252	755	4	66.1	4	76.2	4	53.2	4	51.0	4	62.3	61.8	5	104.4
Colsess	2792	772	---	------	---	------	4	57.9	4	59.2	4	66.7	------	3	111.2
Regal	5030	742	---	------	---	------	4	71.5	4	59.2	4	76.9	------	3	125.6
Glabron	4577	718	---	------	---	------	---	------	4	53.3	4	60.8	------	2	103.4
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	4	40.4	4	46.3	------	2	78.5
Plumage Archer	5033	806	---	------	---	------	---	------	4	46.2	4	50.2	------	2	87.3
Sol (Sixty-Day)	5031	782	---	------	---	------	---	------	4	56.5	4	44.2	------	2	91.2
Sans Barb	5970	746	---	------	---	------	---	------	---	------	4	51.5	------	1	86.7
Scott:															
Albert (Ottawa 54)	4852	701	4	50.8	4	40.4	4	16.8	4	58.0	4	24.4	38.1	5	83.7
Bark	2793	703	4	71.8	4	33.6	4	7.5	4	35.8	4	44.6	38.7	5	85.0
Bearer (Ottawa 475)	4707	704	4	79.7	4	43.8	4	10.2	4	49.2	4	48.1	46.2	5	101.5
Canadian Thorpe	740	816	4	64.5	4	40.7	4	11.5	4	39.9	4	41.2	39.6	5	86.9
Charlottetown 80	2732	817	4	60.9	4	65.5	4	18.0	4	54.7	4	50.8	50.0	5	109.8
Duckbill (Ottawa 57)	1916	826	4	43.5	4	44.3	4	6.7	4	33.9	4	28.8	31.4	5	69.1
Early Chevalier (Ottawa 51)	2725	821	4	71.7	4	31.4	4	14.0	4	48.4	4	41.8	41.5	5	91.1
Gold	1145	829	4	63.5	4	62.1	4	20.7	4	37.6	4	54.8	47.7	5	104.9
Hannchen	531	837	4	69.3	4	64.4	4	18.0	4	60.8	4	59.7	54.4	5	119.6
Himalayan (Ottawa 59)	4838	765	4	72.1	4	56.0	4	19.7	4	51.4	4	45.1	48.9	5	107.4
Manchurian (Ottawa 50)	4832	726	4	73.8	4	50.9	4	5.6	4	29.6	4	39.7	39.9	5	87.7
Mensury (Ottawa 60)	4696	730	4	84.2	4	48.3	4	6.4	4	54.9	4	36.2	46.0	5	101.1
O.A.C. 21 [1]	1470	734	4	77.1	4	43.4	4	8.8	4	54.5	4	43.7	45.5	5	100.0
O.A.C. 21 (Saskatchewan 228)	4708	735	4	72.4	4	50.3	4	7.1	4	40.5	4	43.1	42.7	5	93.8
Pearl	4834	780	4	53.7	4	21.1	4	14.0	4	39.9	4	37.0	33.1	5	72.8
Star	1701	748	4	84.0	4	66.4	4	11.1	4	51.2	4	51.4	52.8	5	116.1
Trebi	936	753	4	84.7	4	45.1	4	13.1	4	56.7	4	55.4	51.0	5	112.1
Velvet	4252	755	4	69.9	4	63.6	4	7.2	4	46.9	4	42.2	46.0	5	101.0
Colsess	2792	772	---	------	4	44.5	4	19.1	4	64.8	4	48.8	------	4	117.8
Plumage Archer	5033	806	---	------	---	------	4	7.3	4	32.7	4	40.6	------	3	75.3
Binder	4703	810	---	------	---	------	---	------	4	59.7	4	58.3	------	2	120.2
Glabron	4577	718	---	------	---	------	---	------	4	49.3	4	43.6	------	2	94.6
Gordon (Ottawa 55)	4842	833	---	------	---	------	---	------	4	38.7	4	38.0	------	2	78.1
Horn	926	838	---	------	---	------	---	------	4	52.3	4	63.5	------	2	117.9
Regal	5030	742	---	------	---	------	---	------	4	55.3	4	49.4	------	2	106.6
Sol (Sixty-Day)	5031	782	---	------	---	------	---	------	4	55.3	4	34.4	------	2	91.3
Swift Current:															
Albert (Ottawa 54)	4852	701	4	28.3	4	17.3	4	21.4	4	18.8	---	------	21.5	4	58.4
Bearer (Ottawa 475)	4707	704	4	59.0	4	44.3	4	14.4	4	27.5	---	------	36.3	4	98.9
Canadian Thorpe	740	816	4	57.3	4	40.9	4	16.5	4	17.7	---	------	33.1	4	90.2
Charlottetown 80	2732	817	4	63.2	4	51.6	4	22.4	4	21.0	---	------	39.6	4	107.8
Duckbill (Ottawa 57)	1916	826	4	46.7	4	32.2	4	7.8	4	10.2	---	------	24.2	4	66.0
Early Chevalier (Ottawa 51)	2725	821	4	56.1	4	28.1	4	15.8	4	23.8	---	------	31.0	4	84.3
Gold	1145	829	4	57.9	4	58.2	4	34.3	4	22.5	---	------	43.2	4	117.8
Hannchen	531	837	4	60.8	4	51.2	4	27.8	4	22.9	---	------	40.7	4	110.8
Horn	926	838	4	57.3	4	70.0	4	25.8	4	27.3	---	------	45.1	4	122.9
Mensury (Ottawa 60)	4696	730	4	51.4	4	34.0	4	14.5	4	24.6	---	------	31.1	4	84.8
O.A.C. 21 [1]	1470	734	4	55.5	4	48.8	4	18.5	4	24.0	---	------	36.7	4	100.0
O.A.C. 21 (Saskatchewan 228)	4708	735	4	58.5	4	36.3	4	23.0	4	22.3	---	------	35.0	4	95.4
Pearl	4834	780	4	44.9	4	30.7	4	20.9	4	16.3	---	------	28.2	4	76.8
Success	2707	783	4	48.4	4	13.8	4	10.4	4	15.6	---	------	22.1	4	6.01

[1] Standard variety with which others are compared.

TABLE 43.—*Acre yields of varieties of barley grown at the experimental farm at Indian Head, at the experimental stations at Rosthern, Scott, and Swift Current, and at the University of Saskatchewan, Saskatoon, Saskatchewan, in 1 or more of the years 1927–31*—Continued

Station and variety	C. I. no.	Canadian accession no.	Number of plots and acre yield												Number of years grown and yield in comparison with standard variety for comparable years	
			1927		1928		1929		1930		1931		Average yield, 1927–31		Year	Yield
			Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield	Plots	Yield				
Swift Current—Con.				*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	*Bu.*			*Pct.*
Star	1701	748	4	56.7	4	20.1	4	16.4	4	15.0	---	------	27.1		4	73.7
Stella (Ottawa 58)	4851	750	4	53.2	4	28.8	4	15.7	4	15.0	---	------	28.2		4	76.8
Swedish Chevalier	4837	818	4	72.6	4	69.0	4	18.6	4	20.0	---	------	45.1		4	122.8
Velvet	4252	755	4	63.2	4	29.6	4	16.3	4	21.5	---	------	32.7		4	89.0
Plumage Archer	5033	806	---	------	---	------	4	12.0	4	15.4	---	------	------		2	64.5
Sans Barb	5970	746	---	------	---	------	4	26.1	4	29.8	---	------	------		2	131.5
Trebi	936	753	---	------	---	------	4	23.6	4	31.5	---	------	------		2	129.6
Colsess	2792	772	---	------	---	------	---	------	4	27.9	---	------	------		1	116.3
Regal	5030	742	---	------	---	------	---	------	4	30.2	---	------	------		1	125.8
Sol (Sixty-Day)	5031	782	---	------	---	------	---	------	4	21.6	---	------	------		1	90.0
Saskatoon:																
Trebi (Saskatchewan 1605)	936	753	6	91.9	6	115.4	6	42.2	6	68.2	6	49.8	73.5		5	120.6
Hannchen [1] (Saskatchewan 229)	4841	837	6	77.9	6	81.3	6	44.9	6	54.2	6	46.4	60.9		5	100.0
O.A.C. 21 (Saskatchewan 228)	4708	735	6	63.3	6	85.0	6	27.9	6	57.3	---	------	------		4	90.4
Colsess (Saskatchewan 1636)	2792	772	6	79.8	6	89.7	6	36.0	6	61.9	6	36.9	60.9		5	99.9
Regal (Saskatchewan 1865)	5030	742	6	64.9	6	107.8	6	44.4	6	70.8	6	42.2	66.0		5	108.3
Sol (Sixty-Day) (Saskatchewan 1667)	5031	782	6	43.5	6	55.3	6	19.0	6	43.7	---	------	------		4	62.5
Sandrel (Saskatchewan 822)	937	745	6	86.6	6	95.7	6	34.4	4	50.6	---	------	------		4	103.5
Duckbill (Saskatchewan 1639)	1916	826	4	70.0	6	59.3	6	18.1	4	46.4	---	------	------		4	75.0
Horn (Saskatchewan 2020)	926	838	---	------	6	63.4	4	33.7	4	55.0	---	------	------		3	84.3
Bearer (Ottawa 475) (Saskatchewan 1222)	4707	704	---	------	6	72.8	6	28.5	4	33.9	---	------	------		3	74.9

[1] Standard variety with which others are compared.

EXPERIMENTAL STATION, SCOTT

G. D. MATHEWS, *Superintendent*

The yields reported from Scott (table 43) show that Hannchen (C.I. 531) has been the best variety during the past 5 years. Its performance has been so consistent that, considering only the results at Scott, there seems no reason for mentioning a second choice. Hannchen is recommended to barley growers. Barley should be seeded the second week in May at the rate of 6 pecks per acre.

EXPERIMENTAL STATION, SWIFT CURRENT

J. G. TAGGART, *Superintendent*

The two-rowed varieties made a slightly better showing than the six-rowed varieties at Swift Current for the years reported in table 43. In yield, Hannchen (C.I. 531) and Gold are the leading two-rowed

varieties, and Trebi and O.A.C. 21 (C.I. 1470) are the leading six-rowed varieties. Based on long-time records, Hannchen and Trebi are recommended. Barley should be planted about May 5 to 10 at the rate of 6 pecks per acre.

UNIVERSITY OF SASKATCHEWAN, SASKATOON

MANLEY CHAMPLIN, *senior professor*, and J. B. HARRINGTON, *Cereal Breeding and Variety Testing, Field Husbandry Department*

Trebi and Regal have produced high yields at Saskatoon (table 43). Hannchen has continued to yield well. Trebi, Hannchen (C.I. 4841), Regal, and Colsess are recommended to growers. Trebi is recommended for the whole of Saskatchewan and Hannchen for the western sections. Colsess has shown promise as a feed barley, and Regal gives indication of being valuable for both feed and malting. Of the varieties mentioned, Regal is the most likely to satisfy Canadian maltsters. Barley should be seeded in May at the rate of 6 pecks per acre.

OUTSTANDING VARIETIES

The position of the better varieties as shown by tests in the United States and Canada is represented in table 44. The second and fourth columns are based on actual yields for the 5-year period. In the second column is recorded the highest yielding variety at each place and in the fourth column is shown the next highest yielding variety. The seventh column is not dependable, but serves to call attention to some of the newer sorts. The tests were for shorter periods and the choice of varieties was arbitrarily made, as in many cases other varieties could be substituted with equal grounds.

Trebi produced the highest average yield at 31 stations. Bearer and Alpha were the leading varieties at 4 stations, while Horn, Club Mariout, and Velvet were best at 3. Although Hannchen led at only 2 stations, this variety and Velvet earn a higher rating, if second places are considered, as they ranked second in 12 and 7 instances, respectively. The only other varieties to place second at more than 3 places were Trebi at 11 and Horn at 6.

Of the newer varieties, Wisconsin Pedigree 38, Regal, Glabron, and other smooth-awned sorts, as yet unnamed, are rapidly assuming importance.

TABLE 44.—*Outstanding varieties grown at the experiment stations in the United States and Canada in the years 1927–31*

Station	5-year period, 1927–31				Showing promise in less than 5 years but more than 1 year		
	Best variety	C.I. or State no.	Second best variety	C.I. or State no.	Number of years	Variety	C.I. or State no.
Mesa, Ariz.	Common Six-Row	4625	Trebi	936	4	Sacramento	4108.
Sacaton, Ariz.	Club Mariout	261	do	936	3	Vaughn	1367.
Fayetteville, Ark.	Selection 6 (Ky.)	4678	Union Winter (Ky.)	583			
Davis, Calif.	Vaughn	1367	Sacramento	4108	3	Paso	5047.
Fort Collins, Colo.	Trebi	936	Hannchen	531	3	Atlas	4118.
Fort Lewis, Colo.[1]	do	936	Coast	2791	2	Arequipa	1256.
Akron, Colo.	Club Mariout	261	Vance (White Smyrna)	4585	4	Comfort	4578.
Athens, Ga.	Greece	4593	Argentine	4594			
Tifton, Ga.[1]	Tennessee Winter, selection 66.	3546	Greece	4593	3	Nakano Wase	2164.
Experiment, Ga.	Greece	Ga. 168	Tennessee Winter Hooded.	Ga. 184	4	Tennessee Winter	Ga. 169.
Moscow, Idaho (spring)	Trebi	936	White Smyrna	910	3	Ace	1853.
Moscow, Idaho (winter)	Winter Club	488			4	Michigan Winter	2036.
Aberdeen, Idaho	Trebi	936	Flynn	1311	4	Arequipa	1256.
Felt, Idaho	Meloy	1176	Trebi	936			
Sandpoint, Idaho	Han River	206	Horsford	4665	3	Hannchen	531.
Urbana, Ill.	Lion	923	Velvet	4252	4	Wisconsin Pedigree 37.	5028.
De Kalb, Ill.	do	923	do	4252	3	do	5028.
La Fayette, Ind. (spring)	Alpha	959	Trebi	936	2	Wisconsin Pedigree 38.	5105.
La Fayette, Ind. (winter)	Purdue 21	4581	Purdue 1101	4582			
Ames, Iowa[1]	Trebi	936	Velvet	4252	3	Spartan	5027.
Mason City, Iowa					3	Trebi	936.
Hays, Kans.	White Smyrna	195	Flynn	1311	4	Vaughn	1367.
Colby, Kans.	Colby Six-Rowed	5919	do	1311	4	Huntington	4110.
Garden City, Kans.					3	Club Mariout	261.
Tribune, Kans.	Flynn	1311	Club Mariout	261	3	Stavropol H. C. 249	5913.
Manhattan, Kans.					3	Flynn	1311.
East Lansing, Mich.[1]	Alpha	959	Michigan Two-Row	2782	4	Glabron	4577.
St. Paul, Minn.	Trebi	936	Smooth Awn	5998 (Minn. 462)			
Duluth, Minn.	do	936	Manchuria×Smooth Awn.	4667 (Minn. 457)	3	Svanhals×Lion	6000 (Minn. 475).
Waseca, Minn.	do	936	Smooth Awn	5998 (Minn. 462)	3	do	6000 (Minn. 475).
Grand Rapids, Minn.	Svansota	1907	Manchuria×Smooth Awn.	4667 (Minn. 457)	4	Smooth Awn	5998 (Minn. 462).
Morris, Minn.	Trebi	936	Svansota	1907	3	Svanhals×Lion	6000 (Minn. 475).
Crookston, Minn.[1]	Smooth Awn	5998 (Minn. 462)	do	1907	3	do	6000 (Minn. 475).
Columbia, Mo.					3	Limerick	1302.
Grain Valley, Mo.					2	Trebi	936.
Maryville, Mo.					2	do	936.

Bozeman, Mont	Trebi	936	B×White Club B	4674	2	Atlas	4118.
Moccasin, Mont	Coast	690	Horn	926	4	Trebi	936.
Havre, Mont	Horn	926	Trebi	936	4	Spartan	5027.
Huntley, Mont	Trebi	936	Horn	926			
Lincoln, Nebr	do	936	Glabron	4577	4	Wisconsin Pedigree 37.	5028.
North Platte, Nebr	Short Comfort	5907	Trebi	936	3	North Platte No. 4	5488.
New Brunswick, N.J	Alpha	959	do.[1]	936	3	Bon Ami	4664.
State College, N.Mex. (spring)	Hanna	2788	Colsess	2792			
State College, N.Mex. (winter)	Unnamed	4673	Unnamed	4672			
Capulin, N.Mex	Club Mariout	261	White Smyrna [1]	195	4	Stavropol	2103.
Ithaca, N.Y	Unnamed State selection 106–181.		Unnamed State selection 104–37.		4	Unnamed	(Cornell 2A–22–420–3).
Statesville, N.C					3	Rowan (North Carolina).	5672.
Fargo, N.Dak	Trebi	936	Hannchen	531	4	Svansota	1907.
Edgeley, N.Dak	do	936	do	531	4	Odessa	182.
Hettinger, N.Dak.[1]	do	936	do	531	3	Velvet	4252.
Langdon, N.Dak	do	936	do	531	2	Wisconsin Pedigree 37.	5028.
Williston, N.Dak	do	936	do	531	4	Glabron	4577.
Mandan, N.Dak	do	936	Odessa	182	3	do	4577.
Dickinson, N.Dak	Steigum	907	Lion	923	4	do	4577.
Wooster, Ohio	Velvet	4252	Horn	926	4	do	4577.
Columbus, Ohio	Trebi	936	Featherston	1120	3	do	4577.
Paulding County, Ohio	Glabron	4577	Oderbrucker	836	4	Trebi	936.
Miami County, Ohio	Oderbrucker	836	Velvet	4252	3	Glabron	4577.
Madison County, Ohio	Velvet	4252	Oderbrucker	836	3	do	4577.
Hamilton County, Ohio	Oderbrucker	836	Velvet [1]	4252	3	Spartan	5027.
Stillwater, Okla.[1]	Tenkow	646	Hero	1286	4	Limerick	1302.
Ardmore, Okla					2	Vaughn	1367.
Lawton, Okla	Han River	206	Pidor	901	4	Tennessee Winter Selection 66.	3546.
Corvallis, Oreg. (spring) upland	Hannchen	531	O.A.C. No. 7	2814	4	Ben Beardless	4687.
Corvallis, Oreg. (spring) bottomland.[1]	O.A.C. No. 7	2814	Ben Beardless	4687	3	Trebi	936.
Corvallis, Oreg. (winter) [1]	O.A.C. No. 7 Selection 6.	5954	Alaska	4106			
Moro, Oreg	Trebi	936	Peruvian	935	4	Flynn Selection 1	5911.
Union, Oreg	do	936	Blue	1247	4	O.A.C. No. 7	2814.
Burns, Oreg	do	936	O.A.C. No. 7 [1]	2814			
Pendleton, Oreg					3	Trebi	936.
State College, Pa	Comfort	4578	Velvet	4252	2	Wisconsin Pedigree 38.	5105.
Clemson College, S.C	Winter Bearded		Awnless	4693	4	Awnless	4694.
Brookings, S.Dak	Odessa	182	Trebi	936			
Eureka, S.Dak.[1]	do	182					
Highmore, S.Dak	Lion×Manchuria	6001 (S.Dak. 1340)	Coast×Lion	6002 (S.Dak. 1343)	4	Glabron	4577.
Ardmore, S.Dak	White Smyrna	658	Horn	926	4	Ace	1853.
Newell, S.Dak	Trebi	936	White Smyrna	195			

[1] Yields for 4 years only.

TABLE 44.—*Outstanding varieties grown at the experiment stations in the United States and Canada in the years 1927–31*—Continued

Station	5-year period, 1927–31				Showing promise in less than 5 years but more than 1 year		
	Best variety	C.I. or State no.	Second best variety	C.I. or State no.	Number of years	Variety	C.I. or State no.
Redfield, S.Dak.					3	White Smyrna	658.
Knoxville, Tenn.	Tennessee Winter Selection 52.	3543	Union Winter	583			
Denton, Tex.					2	Finley (local)	5901.
San Antonio, Tex.	Texas Winter	554	Hannchen	531	3	Vaughn	1367.
Logan, Utah	Atlas	4118	Unnamed	Colorado 3154	2	Sacramento	4108.
Rosslyn, Va. (Arlington Experiment Farm).	Esaw	4690	Tennessee Winter Selection 12.	3534			
Pullman, Wash. (spring)	Blue	1247	Beldi Giant	2777			
Pullman Wash. (winter)	Winter Club	592	Wisconsin Winter	519			
Prosser, Wash.	Blue	1247	Trebi [1]	936	4	Beldi Giant	2777.
Lind, Wash.	Beldi Giant	2777	Meloy	1176			
Morgantown, W.Va.	Alpha	959	Manchuria	244			
Madison, Wis.	Glabron	4577	Comfort	4578	4	Wisconsin Hybrid	5944.
Laramie, Wyo. (irrigated)	Horn	926	Odessa	182			
Archer, Wyo. (dry land)	Coast	690	Trebi	936	2	Vaughn	1367.
Sheridan, Wyo. (dry land)	Trebi	936	Horn	926	3	do	1367.
Lethbridge, Alberta (irrigated)	do	936	Hannchen	531	2	Regal	5030.
Lethbridge, Alberta (dry land)	do	936	do	531	2	Hanna	5975.
Lacombe, Alberta [1]	do	936	do	531	2	Regal	5030.
Beaverlodge, Alberta	do	936	Star	1701	2	do	5030.
Fort Vermilion, Alberta	Manchurian (Ottawa 50).	4832	Albert	4852	3	Plumage Archer	5033.
Edmonton, Alberta	265×O.A.C. 21		Trebi	936	2	Star	1701.
Agassiz, British Columbia [1]	Bearer	4707	O.A.C. 21	1470	3	Trebi	936.
Sydney, British Columbia	Gold	1145	Bearer	4707	3	Charlottetown 80	2732.
Brandon, Manitoba	Star	1701	Velvet	4252	3	Regal	5030.
Morden, Manitoba [1]	Trebi	936	Mensury	4696	4	Velvet	4252.
Fredericton, New Brunswick	O.A.C. 21	1470	Bearer	4707	4	Trebi	936.
Nappan, Nova Scotia	Manchurian (C.R. 14)	4833	Charlottetown 80	2732	4	do	936.
Ottawa, Ontario	Early Chevalier	2725	Manchurian (C.R. 14)	4833	4	do	936.
Kapuskasing, Ontario	Binder	4703	Hannchen	531	4	do	936.
Guelph, Ontario	Velvet	4252	Bearer	4707			
Charlottetown, Prince Edward Island	Charlottetown 80	2732	O.A.C. 21	1470	2	Binder	4703.
Cap Rouge, Quebec	Bearer	4707	Mensury	4696	2	Trebi	936.
Lennoxville, Quebec [1]	Charlottetown 80	2732	Manchurian (C.R. 14)	4833	2	Alpha	959.
Ste. Anne de la Pocatiere, Quebec	Bearer	4707	Star	1701	4	Trebi	936.
MacDonald College, Quebec	do [1]	4707	O.A.C. 21 [1]	1470		Charlottetown 80 [2]	2732.
Indian Head, Saskatchewan	Maltster	585	Hannchen	531	4	Trebi	936.
Rosthern, Saskatchewan	Trebi	936	Horn	926	3	Regal	5030.
Scott, Saskatchewan	Hannchen	531	Star	1701	2	Binder	4703.
Swift Current, Saskatchewan [1]	Horn	926	Swedish Chevalier	4837	2	Sans Barb	5970.
Saskatoon, Saskatchewan	Trebi	936	Regal	5030	4	Sandrel	937.

[1] Yields for 4 years only.

[2] Yields for 5 years in separate test of 2-rowed varieties.

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Mensury (*4696)	35, 36, 37, 38, 39, 40, 41, 42, 43, 44
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Molu (*3210–2)	29
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Monck (*5971)	38, 40, 42
Montana No. 1573 (*4579)	23
Nakano Wase	5
C.I. 754	27, 30
2164	5, 44
2166	30
Nekludowi (*1000)	13, 22
Nepal:	
C.I. 262	20, 26, 32
595	4, 6, 14, 20, 21, 23, 26, 34
4878	40
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New Composite Cross (*5461)	10, 14, 20, 26, 30, 31
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New White Hull-less (*4878)	40
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C.I. 1470	4, 9, 15, 20, 21, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44
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C.I. 836	21, 24, 44
940	13
969	13
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1529	26
2700	40
4666	33
Odessa:	
C.I. 182	10, 14, 15, 17, 20, 22, 23, 26, 34, 44
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974	13
O. K. Beardless	18
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Orel:	
C.I. 351	1, 2, 6, 20, 22, 23, 27, 28, 30
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Oso (*5046)	3
Ottawa No. 7 (*5977)	6
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Pryor:	
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Sebzavar (*4156–2)	29
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5948	3
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Victory (*5077)	4, 18, 23
Vitz (*1306)	13
Vulgare × Smooth Awn (*4646)	15
White Gatami (*920)	20, 22, 26
White Hull-less	6
White Smyrna:	
C.I. 195	1, 10, 14, 17, 22, 26, 34, 35, 44
658	20, 23, 26, 34, 44
910	6, 22, 29, 34, 44
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STUDIES ON THE MEXICAN FRUIT FLY, ANASTREPHA LUDENS (LOEW)

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INTRODUCTION

During the period when the authors were stationed at the laboratory in Mexico City maintained by the Bureau of Entomology of the United States Department of Agriculture in cooperation with the Mexican Department of Agriculture, they carried on a number of investigations on the Mexican fruit fly, *Anastrepha ludens* (Loew). These studies covered a variety of subjects on the biology of the fly, its parasites, and its responses under various conditions to various materials. The results of the studies on the effect of high and low temperatures on this fruit fly have already been published (*6*).[3] The results of studies on five other general subjects appear in the present bulletin.

HYDROGEN-ION CONCENTRATION OF SOIL IN RELATION TO THE PUPATION OF ANASTREPHA

In making field collections of pupae of *Anastrepha striata* which had migrated as larvae from fallen guavas, the authors were struck by the fact that the pupae were to be found lying practically equidistant from the center of each fruit, at a depth which varied slightly with the moisture of the soil. Very rarely was a pupa to be found directly underneath a fruit. Determinations of the hydrogen-ion concentration of the soil under the fruit and out to the pupae gave a gradient starting with pH values as low as 3.6 underneath the

[1] Resigned June 30, 1931. This manuscript is based on work done while the author was connected with the old Division of Tropical, Subtropical, and Ornamental Plant Insects of the Bureau of Entomology and in charge of the laboratory at Mexico City.

[2] Resigned June 30, 1931.

[3] Italic numbers in parentheses refer to Literature Cited, p. 19.

fruit and ending with 7.2 in the neighborhood of the pupae. In other words, the acids of the fruit had soaked out into the previously alkaline soil and produced a pH gradient. Examples of the pH values found are given in table 1.

TABLE 1.—*Hydrogen-ion concentrations of fallen guavas and surrounding soil*

Fruit (pH)	pH of soil (at stated distances in centimeters from center of fruit)				
	0	1.5	3.0	4.5	10.0
	pH	*pH*	*pH*	*pH*	*pH*
3.8	4.2	4.4	6.2	7.2	7.3
3.6	4.4	4.4	6.4	7.2	7.4
4.2	6.6	7.0	7.2	7.2	7.4

From the above observations two lines of experimentation were drafted: (1) On the extent of the acid changes in fruits; and (2), on the sensitivity of Anastrepha larvae to the hydrogen-ion concentration.

The original observations were made underneath guavas, which was fortunate, as they showed the most marked acidity changes of any fruit studied. The guava when ripe gives a reaction of pH 3.8 to 4.2. As the fruit lies on the ground and begins to rot, the pH drops to about 3.0. The larvae leave during this change, especially if there is much moisture in the fruit. The fruit maintains this low point (pH 3.0) for a few days, and then the pH starts to climb. It finally reaches equilibrium in the vicinity of pH 6.0. The mango does not undergo any striking changes in pH, but may reach a low figure of pH 3.0. The sweet lime has an original pH of 5.8, and rarely, while decomposing, reaches pH 4.0. As larvae do not migrate from all of these fruits at the same pH, it is likely that the type of acid also plays a part. The pH of guavas indicates when the larvae may be expected to leave. It must be remembered that in this case we are dealing with *A. striata* Schiner, which shows a greater sensitivity to acids than *A. ludens*.

The sensitivity of larvae to the hydrogen-ion concentration was investigated in the following experiments. Full-grown larvae of *A. ludens* were distributed as evenly as possible on petri dishes of soil (pH 7.8) which had been acidified in the center to pH 2.6 with hydrochloric acid. When the pupae were collected subsequently, they were all found in the periphery of the dish, where the soil had a pH of 7.8. To offset any chance of the above results being due to some tropistic response to light or to the glass surface, the experiment was repeated in reverse. In this case the same number of larvae were placed in dishes acidified peripherally to about pH 2.6. They all pupated in the center. Acetic acid produced substantially similar results. It was clear from the above that larvae migrate away from areas of high acidity in order to pupate. This behavior is in direct agreement with the previous studies on rotting fruit in the field. The writers have also observed a similar response to acids by larvae of *Drosophila melanogaster*.

The influence of the hydrogen-ion concentration was studied also by keeping fully grown larvae of *A. ludens* in Petri dishes on moist

paper of definite reaction. In this method the time taken for puparium formation under such conditions was used as the criterion of the effect of the medium. The results are given in table 2. Lowering the pH to 4.5 did not increase the death rate of either larvae or pupae above the normal expectancy, but the time taken to pupate was three times what it was at pH 8.7. Lowering the pH to 3.2 or 2.0 showed no further effect on the length of time necessary for all the larvae to pupate, but it had two other results. They either pupated at once, to emerge as normal flies, or they took a long time to pupate, and the longer the time the greater the mortality within the puparium.

TABLE 2.—*The effect of the hydrogen-ion concentration on the time necessary for puparium formation in Anastrepha ludens*

pH	Maximum days	Larvae	Dead larvae	pH	Maximum days	Larvae	Dead larvae
	Number	*Number*	*Percent*		*Number*	*Number*	*Percent*
8.7	5	383	3	4.5	17	136	5
6.2	11	209	6	3.2	17	302	11
5.0	14	190	5	2.0	17	273	24
4.8	14	180	7				

With the foregoing data in mind, it is not strange that the sour lime, with a pH of about 2.0, is never infested. Such is also the case with the sidra, another citrus fruit which has a thick inner rind somewhat like a grapefruit and a small juicy center with a pH of about 2.0. Information on the effect that the hydrogen-ion concentration has on the immature stages of the fly suggests that this factor affects the distribution and relative abundance of the fly in Mexico both as to location and host fruit. In many of the regions of infestation visited by Elizabeth Skwarra and the authors, soil reactions were almost all alkaline or on the border line of neutrality. In a few sections where no infestations were found, however, the soil reactions were slightly acid. The means by which soil reaction affects infestation would seem to be indirect. The authors have, however, observed larvae moving considerable distances over areas of unfavorable soil in search of more suitable locations for pupation, and the longer the distance traversed the greater the chance of destruction by natural enemies. The reduction in numbers surviving would in time affect the distribution of the fly.

THE LENGTH OF LIFE OF ANASTREPHA LUDENS

The length of life of *Anastrepha ludens* is a subject of economic importance to the citrus growers of the Rio Grande Valley for the following reason: One of the earliest methods adopted of controlling the fly population (and which is still in use) was to remove completely all fruit from the trees for a certain period each year. In this way adult flies would have no place to deposit eggs and thus produce a new generation, and would themselves die off before the advent of the new crop. The question then arose as to whether adult flies could possibly live over this period and oviposit successfully in the new crop. The answer to this question is given in detail below.

The situation in Mexico itself is totally different. There is no large area in the fly-infested zones given over to a single fruit crop, such as oranges or grapefruit. There are side by side several host fruits of the fly, such as sweet limes, mangoes, oranges, and guavas, all growing in one orchard. This furnishes the fly with a continuous supply of fruits, both for food and oviposition. Even a single mango tree may be in continuous bloom for several months, first on one side and then on the other. The length of life of the fly is therefore of little importance to Mexico under the present conditions of fruit culture.

Previous to these studies very little information was available as to the length of life of the adults. It was the general opinion, however, that they did not live more than 6 months. If such had been the case, a host-free period of 7 months, as established in the Rio Grande Valley, would in itself have been a very effective means of eradication.

There is no way of determining the length of life of an adult fly in the field. The best that can be done is to determine the longest possible survival under laboratory conditions, and consider that as at least a possible value. Many thousands of *Anastrepha ludens* have been maintained in the laboratory for various lengths of time. The standard technic developed consisted in keeping the flies in cages of various types with pieces of cut ripe orange as food and a separate water supply in saturated absorbent cotton. The fruit was changed every second or third day, depending upon the rate of drying and the growth of molds on the fruit. Fresh water was added daily. The room in which the flies were kept had a temperature of 20° to 22° C. (68° to 71.6° F.), rarely falling below 18° (64.4° F.) and rarely rising above 25° (77° F.). The humidity was much more variable, in the dry months ranging from 20 to 35 percent saturation, in the rainy months from 50 to 70 percent. However, the flies were at no time left without a supply of water in the cages. For this reason the humidity in the cages tended to be higher than that in the room generally. This was especially true in the case of "closed" cages, where only one side permitted the passage of air, and this through closely woven muslin. In these the humidity was probably much more constant, as well as higher, than that of the room.

Table 3 is a compilation of the ages over 5 months attained by all flies of which any record was kept. It is by no means complete, and it does not represent the last part of the age distribution in its entirety. It does, however, show that some flies can survive for these periods of time, and that males in general live longer than females.

TABLE 3.—*The numbers of adults of Anastrepha ludens that attained various ages over 5 months under laboratory conditions*

Sex	Number of insects of indicated age in months								
	6	7	8	9	10	11	12	13	14
Females	25	20	15	10	7	3			
Males	143	126	[1] 104	[2] 45	18	7	2	2	1

[1] 54 of these were destroyed deliberately.
[2] 10 of these were destroyed deliberately.

The age at death, as distributed over a whole population of flies, was determined by detailed records kept on relatively small numbers of individuals. The experiments recorded in Figures 1, 2, and 3 were made in wooden boxes painted white, inside capacity 7½ by 1½ by 4½ inches, with the top of glass and one side of heavy muslin. Food and water supply were as previously described, which was the standard for these studies.

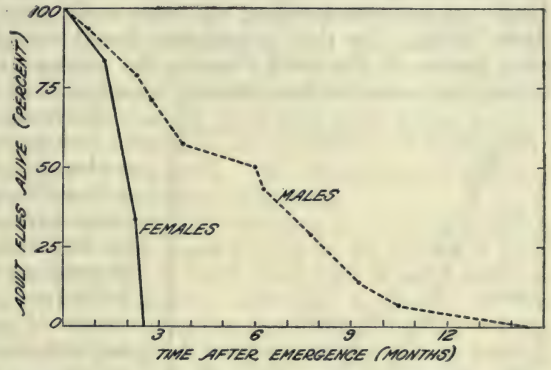

FIGURE 1.—Length of life in a group of 12 female and 14 male adults of *Anastrepha ludens*.

Figure 4 represents the dying off of a much larger group of flies (250 females and 220 males) kept in a much larger cage (1 by 1 by 2 feet). The detailed record in this case was not started until the flies were 2 months old. In general, the graph is similar to the others; and all show that males live longer than females. This is true both for the extreme cases and for the bulk of the population.

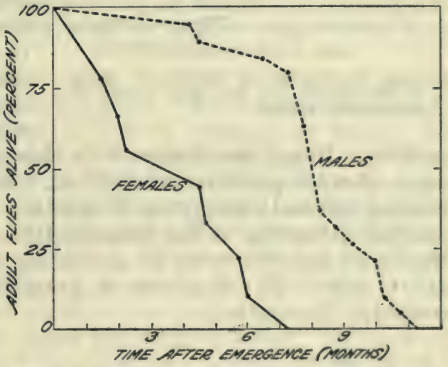

FIGURE 2.—Length of life in a group of 9 female and 19 male adults of *Anastrepha ludens*.

A reason which suggests itself for the early death of females under cage conditions is the twofold relationship between females and fruit, as compared with the single relationship between males and fruit. In the case of males, fruit is used for nutrition only. In the case of females it is also a medium in which to oviposit. Caged flies mate freely, and the females frequently oviposit in pieces of

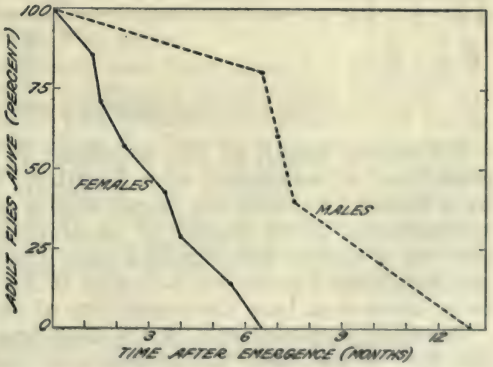

FIGURE 3.—Length of life in a group of 7 female and 5 male adults of *Anastrepha ludens*.

orange [4] (with rind), as well as in crevices or on the sides of the cage. It is entirely possible that there is some injury to females ovipositing in ripe orange, although fruit in this form is entirely suitable as food; or the withholding of their eggs may fundamentally affect their health. On this hypothesis, females might be expected to live even longer in the field than in the laboratory, without, of course, taking into account the presence or absence of natural enemies.

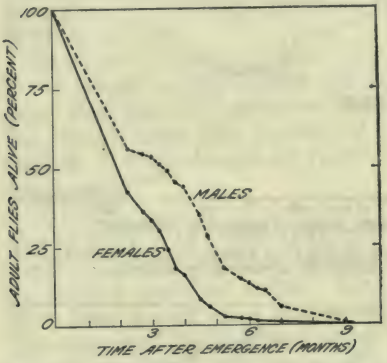

FIGURE 4.—Length of life in a group of 250 female and 220 male adults of *Anastrepha ludens*.

Since adult females are known to live as long as 11 months, and males still longer, it is clear that a host-free period between annual crops cannot in itself be effective in eradicating the fly. However, depending on the length of the fruit-free period, there is a decrease of population due to this method of attack. Just what percentage, may be guessed at by reference to figure 4. But if to the length of life of the adult fly there is added the time passed in egg, larval, and pupal development, it will be seen that a considerable proportion of the total number of flies can be expected to survive. Pupal development in this species can take as long as 100 days, at a temperature of 11.9° C. (53.4° F.), without entirely eliminating normal emergence of adults. This consideration alone adds another 3 months to the possible life of the organism. The possible length of the life cycle of *A. ludens* under laboratory conditions at 21° C (69.8° F.) is given in graphic form in figure 5 and totals, roughly, 13 months.

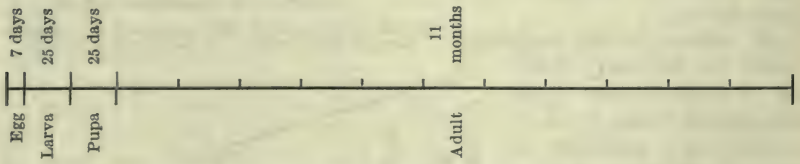

FIGURE 5.—Possible length of life of *Anastrepha ludens* by stages

Of course, length of life as related to fruit infestation has to be considered in connection with fertility. Viable eggs have been laid by a female 7 months old, caged with a male of the same age; while spermatozoa in all stages of development have been observed in sections of a testis taken from a male 9 months old. These, again, are not maximum figures for behavior in the field; and as long as a fly lives, there is at least the possibility of its being fertile.

Another supposed role of the host-free period is that of starving the fly. It has been tacitly assumed that the fly can feed only on

[4] Though the oviposition of the females in the pieces of orange was heavy at times, it would have been instructive to compare it with that of the normal free female. This was impossible owing to the nature of the observations necessary. It must suffice to say, however, that many hundreds of eggs were laid in the cages.

fruit, and that, in the absence of the various hosts, there will be no food supply. Direct observation in two directions has furnished data on the possibility of the fly's survival on foods other than fruit. (1) In the field *Anastrepha ludens* has been observed many times feeding on the outside of unbroken mangoes and guavas, on which there seemed to be no exudate whatever. It was deduced that the flies were feeding on some external growth on the fruit. Similarly, it has been noticed in the laboratory that the flies when feeding frequently pay no attention to freshly cut surfaces of fruit, until the outside has been completely explored. (2) Dissection of the crop of the insect has shown that it contains yeast cells.

If the two foregoing observations are relevant, a nutrient medium suitable for the fly and seeded with yeast should be an adequate food. Such a medium (*2*) was made up of corn meal and Knop's solution and inoculated with a yeast culture. On this a group of flies lived for over 3 months. The difficulty with the food lay in the fact that the flies frequently got stuck in the medium while feeding or buzzing about. This mechanical fault contributed largely to their early death. The above experiments and the field observations on the flies present evidence for the possibility of the fly feeding on any source of yeast that might be available in nature apart from that found on its host fruits.

Another experiment was run in which the flies were given only a lump of sugar and a separate water supply. No attempt was made to keep either the sugar or the water free of bacteria or mold. At the end of 4 months only 30 percent of the total population had died. This figure represents a somewhat better survival than that obtained for flies living on pieces of orange (figs. 1, 2, 3, and 4). In the field honeydew is always present, and yeasts and molds are universally to be found in it and in all plant exudates. The experiments of Delcourt and Guyenot (*7*), Baumberger (*1*), and others have shown that the fruit fly *Drosophila* (*ampelophila*) = *melanogaster* can live on a diet consisting entirely of yeast, either growing or dried. In view of the above facts, the possibility of eliminating a species of fly of this type solely by a host-free period is very remote.

The following facts regarding the adult longevity of *Anastrepha ludens* may be stressed as having an important bearing on the possibility of control through a host-free period.

An adult male and female have been kept alive for 14½ and 11 months, respectively. Under laboratory conditions females die sooner than males. Both males and females have been found fertile after a length of time greater than the host-free period which was established in the Rio Grande Valley. A host-free period between annual crops, depending on its length, can eliminate a varying proportion of the adult population of *A. ludens*. It cannot be expected to effect a complete elimination. The fly can live for long periods on yeasts or sugars whose availability in the field is independent of the presence of host fruits.

THE TOXICITY OF COPPER TO ANASTREPHA LUDENS

In a recent paper (*6*) the writers mentioned the fact that copper chloride, used to keep down the growth of molds in dishes in which pupae were kept, proved to be highly toxic to newly emerged flies if

they were not removed from the dish at once. The quickness of their death and their appearance led to an investigation of the underlying mechanism. The use of copper as an insecticide is well known, and its application in fruit-fly control has been reviewed recently by Miller and McBride (*8*).

In a series of experiments a comparison was made of the toxicity of various compounds of copper, made up in a spray mixture of the following composition:

Granulated sugar	grams	25
Maple sirup	cubic centimeters	50
Copper compound	gram	1
Distilled water	cubic centimeters	1,000

This mixture was fed on saturated absorbent cotton in 2½-inch Petri dishes. It was given fresh every second or third day, with intermediate additions of distilled water to the cotton when necessary. No other (copper-free) food or water was supplied. The temperature of the laboratory was kept within a few degrees of 22° C. (71° F.).

The results (fig. 6) completely confirm the findings of Miller and McBride as to the relative toxicity of the different salts. The toxicity is directly parallel to the concentration of copper ions in each solution. The above authors have shown that the toxicity of copper carbonate increases with acidity. This is simply another way of expressing the concentration of ionic copper. The lower the pH the greater the dissociation of copper carbonate. For instance, at pH3 this salt would be completely dissociated and the carbonate anion decomposed.

Curve *A*, *a* (fig. 6) shows the effect of allowing the solution to age. In what manner it changed the authors cannot say, but when tested against a new copper chloride solution the older one gave a slightly less toxic effect than the freshly made one. The possibility of a reaction between the food materials and the salts would bear investigation.

In another series of experiments the efficacy of copper was studied, different degrees of obligatory feeding being used. Copper chloride was employed, because it supplies the active agent in its most available form. In figure 7 are plotted the lethal curves in several fly populations which had been fed in the following manners, the technic being identical with that described for the previous series: (1) Food and water both poisoned. (2) Water supply, given on cotton as above, poisoned with copper chloride, 1 g per liter. Food consisted of lump sugar, given dry. (3) Water poisoned as in 2. Food consisted of sections of cut orange which, being moist, reduced the necessity for additional water consumption. (4) Controls.

From the curves in figure 7 it is clear that a spray of the type employed by Miller and McBride, to be effective in the field, must contain as much of the toxic agent as possible, to offset the dilution produced by alternative sources of food and water.

The reason for the shape of these curves is unknown. The presence of other fluids (orange juice) would account for the low initial death rate in curve *C*; but why there should be a double inflection in curves *B* and *C* is entirely obscure.

The main interest, however, lay in the mechanism by which the copper produced its effects. *Anastrepha ludens* in its normal habitat feeds largely if not exclusively on yeasts. The flies can be seen feeding on the skins of fruits where there is no rupture or exudation of juice whatever. Under cage conditions, they usually exhaust the possibilities of the skin of freshly cut fruit before examining the cut surface. Furthermore, the writers have kept flies alive and in normal condition (as judged by their subsequent reproduction) for 3 months with a yeast-growing medium as their sole source of nutri-

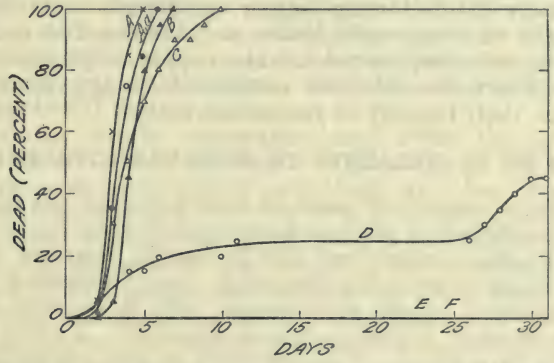

FIGURE 6.—Toxicity of various compounds of copper, fed in a spray mixture, to *Anastrepha ludens*: *A*, Copper chloride (freshly prepared spray); *a*, the same 1 month old; *B*, copper nitrate; *C*, copper sulphate; *D*, copper carbonate; *E*, copper oxide; *F*, control.

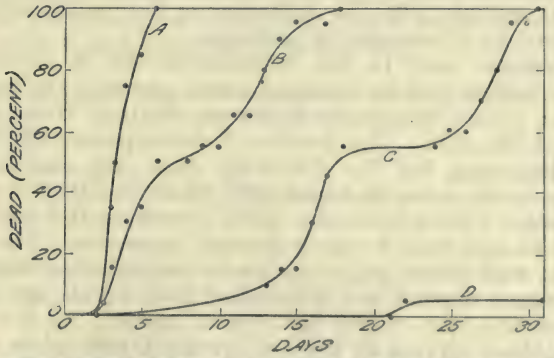

FIGURE 7.—Toxicity of copper chloride to *Anastrepha ludens*: *A*, Food and water poisoned; *B*, water alone poisoned, food dry; *C*, water poisoned, moist food unpoisoned; *D*, control.

ment. *Drosophilia melanogaster*, the vinegar fly, lives on yeasts, dead or alive. It was entirely to be expected that on dissecting out the alimentary tracts of several normal adults living on pieces of cut orange large numbers of yeast cells would be found. In the case of copper-killed flies, the number of yeast cells was greatly diminished, and those present appeared to be dead. In line with this is the observation by Miller and McBride (*8*) that Mediterranean fruit flies fed with copper died off at a rate similar to flies dying of starvation.

All of the above facts suggested the hypothesis that the effect of copper on fruit flies is connected with its toxicity for molds. Further evidence for this idea was obtained by inoculating with mold the spray mixtures used in the series of experiments illustrated in figure 6. The only solutions which showed any growth were the ones which were nontoxic—that is, the copper oxide mixture and the copper-free control. This concept fits in completely with the researches of Cleveland on termites (*4*), which showed that any agency which destroyed the protozoan fauna of the intestine produced death of the termite by starvation.

In this study the following copper compounds were found to be toxic to adults of *Anastrepha ludens* and are listed in order of toxicity: Copper chloride, copper nitrate, copper sulphate, and copper carbonate. The action of these compounds is apparently indirect, depending on their toxicity to yeasts and molds.

TEMPERATURE IN RELATION TO HOST-PARASITE EQUILIBRIUM

The biological control of pests by their parasites has been deemed sufficiently important to warrant large expenditures for that purpose. The fundamentals underlying the biological relations of pest to parasite have, however, quite frequently been overlooked. That the parasite successful in one environment will be equally effective as a control in another, is always open to question. A study was made stressing the importance of temperature in the establishment of a parasite in a new environment. The results of this study suggest that a parasite of little use in one region might be very valuable in another, under different climatic conditions. In this section the authors deal entirely with the difference in the reactions to temperature displayed by a host and its parasite.

The organisms used in the experiments to be described were *Anastrepha ludens* and its hymenopterous parasite *Opius crawfordi* (Vier.) that occurs frequently in larvae obtained from mangoes in the State of Morelos. The details of development of *Opius* have not been described, but the following facts are available. *Opius* lays its eggs in the larva of *Anastrepha* while the latter is still within its host fruit. The *Anastrepha* larva grows to full size, migrates from fruit to soil, and forms a normal puparium. On inspection through the wall of the puparium under suitable conditions, no distinction between normal and parasitized individuals can be detected until almost the end of the last larval instar. At this stage the shiny, annulated surface of the half-grown *Opius* larva can be distinguished, lying alongside of the relatively structureless remains of the *Anastrepha*. By the time pupation proper would have occurred the parasitized *Anastrepha* has completely disappeared, and the *Opius* larva can be seen moving about within the otherwise empty puparial shell. Within a few days the *Opius* pupates, and the fully differentiated imaginal structures can be clearly seen. The pearly white pupa gradually develops the characteristic red and black pigment of the adult, and the imago bites its way through the puparium at more or less the same time that its host would have emerged under the same conditions.

Anastrepha ludens is very abundant at certain times of the year, so it was possible to obtain from the field thousands of mature larvae, a varying proportion of which proved to be parasitized. The numbers of *A. ludens* used were so large (400 to 500 per temperature class) that a significant number of cases for the data on *Opius* was obtained.

Mature larvae were collected from mangoes and allowed to pupate on moist soil. The pupae were collected at intervals, and all those which formed in the course of 24 hours (midnight to midnight) were given the date of that day. As soon as collected the pupae were covered with a centimeter or less of sterile soil in covered Petri dishes. They were incubated at constant temperature (*5*) (see table 5 for range of temperatures used) until emergence took place. With this technic, 95 percent emergence was obtained regularly for *A. ludens* at nonlethal temperatures.

The means by which temperature may affect the host-parasite equilibrium differ. First, the limits of tolerance of the two organisms may be quite different at both high and low temperatures. *Opius* failed to emerge at 30° C. (86° F.), whereas a good emergence (85 percent) was obtained for *Anastrepha* at this temperature. The upper limit for *Anastrepha* was found to be considerably higher; an emergence of 87.4 percent was obtained at about 30.45° C. (86.8° F.), and a few emerged even at 31.4° C. (88.5° F.). *Anastrepha*, therefore, can develop and emerge at a temperature about 2 centigrade degrees higher than *Opius*. The lower extreme produced similar results. At 12.1° C. (53.8° F.) no *Opius* emerged, while 83.6 percent of *Anastrepha* emerged at this temperature. At 14.5° (58.1° F.) only 52 percent of *Opius* emerged, as against 96 percent of *Anastrepha*. The percentage of emergence over a series of temperatures is given in table 4, and graphically in figure 8.

TABLE 4.—*Emergence of Opius crawfordi and Anastrepha ludens at various temperatures*

Temperature		*Opius crawfordi*			*A. ludens* emerged	Temperature		*Opius crawfordi*			*A. ludens* emerged
		Dead	Emerged					Dead	Emerged		
°C.	° F.	*Number*	*Number*	*Percent*	*Percent*	° C.	° F.	*Number*	*Number*	*Percent*	*Percent*
10.0	50.0	-------	0	0	0	25.05	77.1	-------	-------	-------	96.0
11.9	53.4	10	0	0	27.2	26.95	80.5	136	235	63.3	90.5
12.1	53.8	109	0	0	83.6	28.0	82.4	46	42	47.7	97.6
14.5	58.1	56	61	52.1	95.8	29.1	84.4	6	3	33.3	90.1
16.0	60.8	155	135	46.6	96.6	29.95	85.9	27	0	0	84.6
18.0	64.4	32	47	59.5	97.3	30.45	86.8	123	0	0	87.4
19.75	67.5	53	112	67.9	97.3	31.0	87.8	87	0	0	40.6
22.0	71.6	18	60	76.9	97.3	31.4	88.5	112	0	0	.3
24.0	75.2	5	19	79.2	91.9						

The points obtained for *Opius* with *A. ludens* as host were supplemented and supported with data obtained from *A. striata*, another host. The latter points are plotted as black dots in figure 8.

The limits of the range of temperature toleration have been stressed in the above discussion and *Anastrepha* has been found to have a wider range than *Opius*. Attention focused exclusively on the ends, however, gives an incomplete impression of the relation-

ships. If the entire picture, as shown in table 4 and figure 8, is examined there will be found a gradually increasing lethal effect of temperature on *Opius* long before it begins to operate on *Anastrepha*. It would seem from the figures given in table 4 that there is a wide range of temperature (14.5° to 28° C. or 58.1° to 82.4° F.) that is perfectly satisfactory for the development of *A. ludens*. On the other hand, *Opius* passes through a sharp optimum at about 25° C. (77° F.), with a sharp slope on either side. The practical result is that although total mortality of the parasite does not occur at these nonlethal temperatures, a considerable diminution of its numbers takes place. Furthermore, if there is a high death rate it is logical to assume that even some of the survivors are injured in such a way that early death will ensue. This assumption is in line with the findings of Osterhout (*9, p. 18*).

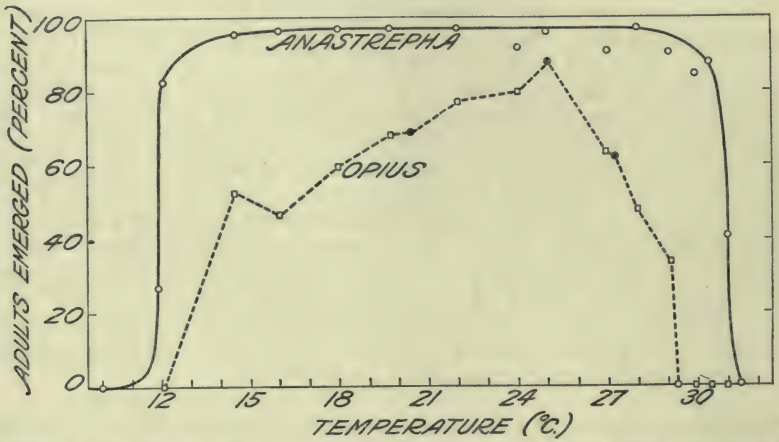

FIGURE 8.—Percentage of emergence of *Anastrepha ludens* and *Opius crawfordi* at different temperatures. The circles indicate emergence of *A. ludens;* the black round dots, emergence of *O. crawfordi* from *A. striata* as host; the squares, emergence from *A. ludens*.

A point which might be raised in connection with figure 8 is the disregard, in the curve for *Anastrepha*, of the points corresponding to 24°, 26.95°, 29°, and 29.95° C. All these points lie below the curve as drawn and are not balanced by other points lying above it. The curve was drawn deliberately above the four points for two reasons: (1) The emergence of the organism in this case is more significant than failure to emerge; that is, whereas there is a greater emergence at 30.45° than at 29.95° C., temperature cannot have been the detrimental factor causing the low emergence at the lower temperature; some other factor must be responsible; (2) this detrimental factor is known, since these experiments were the first run, and the technic of handling the pupae had not been perfected. In the light of this information the writers consider it justifiable to plot the points, but draw the curve above them.

Another wholly different effect of temperature is to be found in the data on the length of time spent within the puparium by the two organisms under consideration. These data are presented in table 5 and figure 9.

TABLE 5.—*The period in puparium of Opius crawfordi and Anastrepha ludens at various temperatures*

Temperature		*Opius* (male)				*Opius* (female)				*Anastrepha*			
		Cases	Period in puparium			Cases	Period in puparium			Cases	Period in puparium		
			Minimum	Maximum	Average		Minimum	Maximum	Average		Minimum	Maximum	Average
° *C.*	° *F.*	*Number*	*Days*	*Days*	*Days*	*Number*	*Days*	*Days*	*Days*	*Number*	*Days*	*Days*	*Days*
11.9 ±0.15	53.4±0.3	(1)	(2)	(2)	-------	(1)	(2)	(2)	-------	171	99	107	102.68
12.1 ± .3	53.8± .6	(1)	(2)	(2)	-------	(1)	(2)	(2)	-------	286	81	94	85.46
14.5 ±1.0	58.1±1.8	11	59	62	59.6	6	65	75	69.0	637	53	65	57.74
16.0 ± .2	60.8± .4	31	39	46	43.6	27	45	52	48.5	570	42	56	45.25
18.0 ± .15	64.4± .3	16	33	37	34.6	15	37	44	38.3	671	33	41	35.62
19.75± .2	67.5± .4	35	22	31	27.2	56	28	34	30.3	874	26	37	28.14
22.0 ± .1	71.6± .2	26	19	22	20.4	34	22	26	23.7	428	20	25	22.02
23.45± .05	74.2± .1	7	19	21	19.7	8	21	24	22.4	750	18	27	20.08
24.0 ± .1	75.2± .2	10	17	19	18.2	9	19	22	20.1	802	17	24	18.33
24.5 ± .1	76.1± .2	15	17	20	18.2	18	19	21	20.1	442	17	22	18.09
25.05± .1	77.1± .2	0	-------	-------	-------	2	19	20	19.5	457	15	21	16.54
25.95± .1	78.7± .2	1	16	16	16.0	0	-------	-------	-------	451	15	20	15.92
26.95± .05	80.5± .1	109	13	18	15.4	103	16	21	17.3	477	14	17	15.01
28.0 ± .05	82.4± .1	20	14	16	15.3	23	15	18	16.5	863	13	16	14.14
29.1 ± .1	84.4± .2	2	15	15	15.0	0	-------	-------	-------	511	12	15	13.55
29.95± .05	85.9± .1	(1)	(2)	(2)	-------	(1)	(2)	(2)	-------	630	12	17	13.17
30.45± .05	86.8± .1	(1)	(2)	(2)	-------	(1)	(2)	(2)	-------	684	12	15	13.17
31.0 ± .1	87.8± .2	(1)	(2)	(2)	-------	(1)	(2)	(2)	-------	[3] 204	12	14	13.10
31.4 ± .1	88.5± .2	(1)	(2)	(2)	-------	(1)	(2)	(2)	-------	[4] 2	13	13	13.00

[1] See table 4 for number of *Opius* dead.
[2] No emergence.
[3] 590 pupae were incubated in this experiment. See table 4 for percent emerged.
[4] 664 pupae were incubated in this experiment. See table 4 for percent emerged.

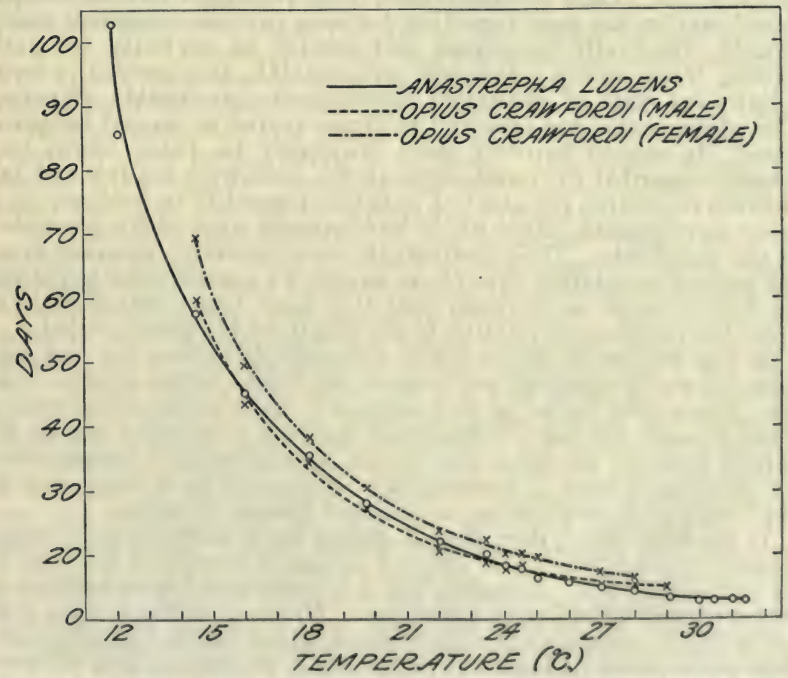

FIGURE 9.—Average length of the period in the puparium of *Anastrepha ludens* and *Opius crawfordi* at various temperatures.

The length of the pupal period of *A. ludens* was recorded in whole days, since the spread in emergence was so wide as to make closer observations insignificant. Pupae formed within 15 minutes of each other and and kept at constant temperature (26.95° ±0.05° C., or 80.5° ±0.1° F.) may be as much as 48 hours apart at emergence.

The figures for males and females have been averaged separately in the case of *Opius*, while for *Anastrepha* a single series of figures is given. This was done because the difference between the sex averages, while invariably present, is very small in the case of *A ludens* (0.4 day at most), and would not show in the graph if plotted on the same scale.

That part of the developmental process under comparison is not strictly equivalent in the two species in a morphological sense. In *Anastrepha* it is the measure of the length of the last larval instar, plus the pupal stage proper. On the other hand, in the case of *Opius* it is known that within the host puparium is passed an undetermined fraction—conceivably all—of the larval life, plus the pupal stage. However, it is a comparison of periods each of which always begins at the same developmental point, so differences in rate of development after that point can properly be attributed to differences in temperature.

A few individual cases have been omitted from the calculations on account of their anomalous behavior. Among parasitized pupae which had failed to produce any adults at the expected time, there was occasionally found a living *Opius* which was still in the larval condition, although all of its contemporaries had completed their development. These delayed larvae, if the puparium was not broken, would stay in the same condition for long periods, sometimes many months, eventually to pupate and emerge as perfectly ordinary looking *Opius* adults. Although not immobile, they seemed to be in a quiescent state of suspended development—presumably diapause. The phenomenon was observed in *Opius* reared at several temperatures. It seemed to occur more frequently in dishes which had become somewhat dry; and although the cases were too few and far between to control, the onset of pupation seemed to be hastened by a moist environment, after which development apparently proceeded at the usual rate. These individuals were so widely aberrant from the general population (one *Opius* emerged 7 months after pupation, its fellows in about 25 days) that they have been omitted entirely from the calculations relating to the length of the pupal period.

It will be seen in figure 9 that although the curves for host and parasite are in a general way similar, the *Opius* curves diverge from the *Anastrepha* curve as they approach their limits of tolerance. That is, near the ends of the range *Opius* is accelerated less or retarded more by the same rise or fall, respectively, of temperature. Its generation time is consequently lengthened more than that of the host, and its effectiveness as a control thereby impaired.

It has been found, then, that *A. ludens* has a wider range of emergence (11°–31.5° C. or 51.8°–88.7° F.) than *O. crawfordi* (12°–29° C. or 53.6°–84.2° F.). *A. ludens* has a wide range of temperatures at which normal development takes place. *Opius*, in contrast, has a peak of optimum development with marked lethal effects on either side. The development of these two organisms is accelerated to a different degree by the same increase in temperature.

From the foregoing data it may be seen that temperature can play a distinct role in the success of a parasite. That other controlling factors exist will be made clear in the next section of this bulletin.

HUMIDITY IN RELATION TO THE SURVIVAL OF OPIUS CRAWFORDI

Anastrepha ludens, in the State of Morelos, is parasitized in its larval stage by *Opius crawfordi*. The possibility of using this organism in the control of *A. ludens* led to a study of its biology. Some of the results, especially the vital role of humidity, are presented here. The contention and evidence of Buxton (*3*) on the role of climatic humidity are further supported by these findings.

At almost all times of the year during the period from 1928 to 1931, inclusive, there was an abundance of mangoes and, therefore, of *Anastrepha* larvae, in the city of Cuernavaca, Mexico, and from these the *Opius* were recovered. It is significant, however, that from the small amount of citrus in this section which is also infested by *A. ludens* no recovery of *Opius* was made. But it must be borne in mind that in the field there is always a great abundance of infested mangoes and guavas, favored fruits, which more than supply the needs of the parasite.

A few general remarks on the behavior of this parasite might help in the breeding of similar organisms. *Opius crawfordi* adults cannot be kept in very small cages or containers—they tear one another to pieces. At the beginning of these studies parasitized pupae were reared and allowed to emerge in Petri dishes, so that they might be handled easily. However, if two or more newly emerged adults were allowed to stay in these dishes for half an hour or so, at least half would be dead and the others seriously mutilated. The system used was to keep the Petri dishes covered (and very moist) until the insects were almost ready to emerge. The dishes were then uncovered and placed in a large cage, where there was plenty of space for the adults to fly about. By simply shifting the dish to a new cage at convenient intervals, the emergences could be easily recorded, and loss by injury was avoided entirely.

To facilitate the separation of the parasitized pupae from the normal fly pupae a study was made of the puparia. It was found that some puparia were markedly darker than others, and that these dark-colored puparia were generally parasitized. An attempt was made to sort out the parasites before emergence, using this criterion. But a few pale puparia yielded parasites, and a few dark ones yielded flies, so the method did not hold absolutely. The foregoing observations were all made on pupae formed and reared in slightly moist soil, under which conditions the puparium is opaque. If, however, the pupae, after formation in moist soil, are washed and placed on wet absorbent cotton in covered Petri dishes, they stay somewhat lighter in color and are quite transparent. The developing insect can be readily observed through the puparium with the aid of a low-powered binocular. On the fifth day of incubation at 25° C. (77° F.), parasites and flies can be identified with complete certainty, as at this stage the *Anastrepha* has become a proper pupa, or the *Opius* larva can be seen moving around inside

the puparium, any remnants of the host larva having completely disappeared.

Adults emerging over a period of a few days were placed in cages and individual records kept of the date of death. The cages in which they were kept had a wooden floor and frame, the top and front of glass, and the other sides covered with muslin. They consequently permitted relatively little air circulation, a point which will be discussed more fully later. The dimensions of the cages were 12 by 12 by 8 inches, and not more than 24 individuals were kept in a cage at one time.

In an attempt to rear *Opius crawfordi* for breeding purposes, difficulty had been experienced in finding a suitable food that would keep the adults alive for more than a few days. Various fruits which are subject to infestation by *Anastrepha ludens*, the host of *Opius*, were supplied as food, with always the same result of death within a few days. Finally, however, the use of ordinary cane lump sugar, with a dish of wet absorbent cotton, met with much better success; and detailed records were started on the length of life of each *Opius*.

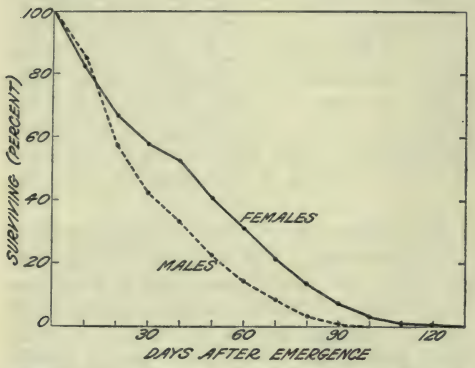

FIGURE 10.—Length of adult life of males and females of *Opius crawfordi*. The records are from 238 females and 133 males.

Figure 10 shows the length of adult life of the entire population of *Opius crawfordi* considered as a whole, with the one exception that males and females are plotted separately. This shows that *Opius* females live longer than the males, both the extreme cases and the bulk of the population.

An analysis was then made of the data of each separate experiment. It was seen that with each experiment the life span of the insect became progressively longer, beginning with the group started in February. To state it another way, the life span of those *Opius* that emerged in February was shorter than that of those which emerged in March and much shorter than that of those emerging in May. As there had been no known change in technic in the course of the observations, the temperature and humidity records for the room in which the insects were kept were examined for a possible explanation. The temperature had been fairly constant, averaging 21° C. (69.8° F.), and without significant fluctuations [5] (fig. 11). The relative humidity, however, had undergone a sharp increase with the advent of the first rains in April and had maintained a consistently higher level since that time. The *Opius* records were therefore divided up into small groups; (1) those which lived only

[5] That the temperature variation (18° to 26° C.) is of little importance is suggested by earlier findings, namely, that good emergence was obtained for *O. crawfordi* when incubated at these temperatures.

during the dry season, (2) those which emerged about a month preceding the rains, and (3) those which emerged after the rains began. Figure 10 shows the dying off of each of these three groups, considered in relation to their dates of emergence. In the same graph are included the mean daily temperature and humidity for the period under consideration.

The data in figure 11 are for females only, since there were relatively few males, and the large sex difference has already been commented on. Group 1 comprised 21 cases, emerged February 10 to 18; average, February 15. Group 2 comprised 40 cases, emerged March 18 to 31, average, March 25. Group 3 comprised 50 cases, emerged April 16 to 26; average, April 21.

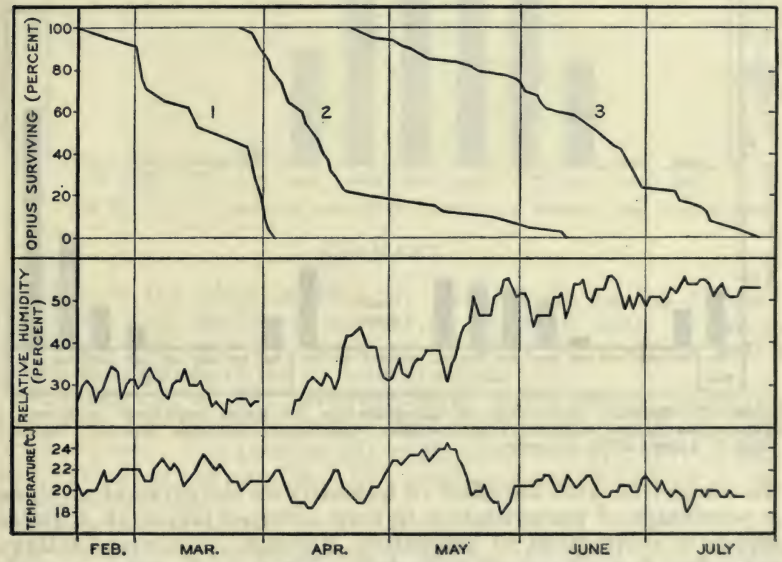

FIGURE 11.—Relation of the length of life of *Opius crawfordi* to temperature and humidity. The insects represented by curve 1 lived entirely in the dry season, those in curve 2 emerged about 1 month preceding the rains, and those in curve 3 lived in the rainy season.

It will be seen that the slopes of the curves for group 1 and for the first part of group 2 are quite similar and that they correspond with a consistently low relative humidity—30 percent on the average. Coincident with the first rainfall, April 19, there is a sharp rise in humidity and a break in curve 2. Subsequent to this date curve 2 is much more nearly parallel to curve 3, in spite of the fact that group 2 was nearly a month older than group 3. The steep drop in curve 3 near the end of June was coincident with the accidental drying up of the dishes of water in the cages, a circumstance which serves to emphasize the importance of moisture to this organism.

As mentioned above, the cages permitted very little air circulation. For this reason, with a constant supply of water in each cage, the humidity inside them was probably somewhat higher than that out in the room. From the humidity record of the room alone, there seems to be a critical point in the neighborhood of 30 percent, below

which *Opius* dies off much more rapidly than above that point. But the accident mentioned above would indicate that a humidity as low as 50 percent can cause considerable damage, since in the absence of an additional source of moisture the cage humidity would become the same as that prevailing in the room. On this occasion the cage and room humidity had every reason to be identical. It is therefore possible that the cage humidity was normally about 20 points higher than the record, and that the marked improvement in viability corresponds with an increase from 50 percent up, rather than from 30 percent. In any case, in setting up conditions suitable for the survival of this insect, it would be much safer to aim at a humidity higher than 50 percent.

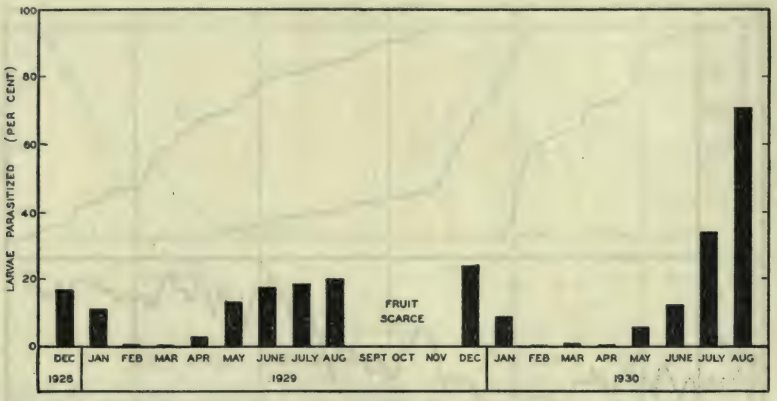

FIGURE 12.—Monthly percentage of parasitization by *Opius crawfordi* in larvae of *Anastrepha ludens* collected from mangoes, Cuernavaca, Morelos, Mexico. December 1928 to August 1930, inclusive.

In connection with the effect of humidity on the survival of *Opius*, the percentage of parasitization in field-collected larvae of *A. ludens* supplies a verification of laboratory findings. *Anastrepha* larvae were taken from mangoes, collected in Cuernavaca twice monthly. These larvae were reared, and the percentage of parasitization for the month was determined. In figure 12 these data from December 1928 to August 1930, inclusive, are placed in graphic form.

The repetition of the history of infestation from one year to the next is clearly shown, even though the magnitude differs somewhat. Unfortunately the humidity and rainfall records for this entire period cannot be obtained. However, the rains generally begin in April and last until October, with a peak in June and July. From November through March there is very little or no rain. There is a steady decline in the parasitization to almost zero, as the dry season advances, followed by an increase with the advent of the rains. A graph of the average rainfall for Cuernavaca, based on observations taken over 9 years, is given in figure 13.

It might possibly be thought that the abundance of parasites is controlled by the number of *Anastrepha* larvae, and this in turn by the quantity of fruit. Such, however, is not the case. There are in Cuernavaca a number of off-season mango trees, which bear during

January, February, and March, and furnish an adequate supply of larvae to be parasitized; but the number of adult *Opius* during those months is so small that the percentage of parasitization is very low. One other confirmation is that of direct observation. In the dry months it is almost impossible to find an *Opius* adult in the field, but in the rainy season they can be observed on trees, on the ground, and on mangoes in all locations.

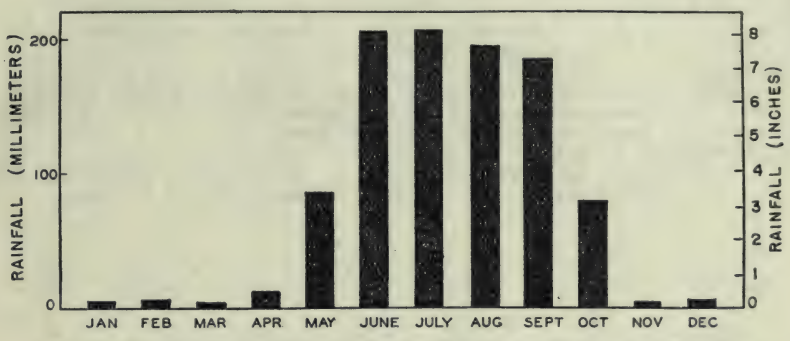

FIGURE 13.—Average monthly rainfall in Cuernavaca, Mexico, over 9 years

SUMMARY

Studies on the Mexican fruit fly, *Anastrepha ludens* (Loew), have shown that the larvae on leaving the fruit avoid as far as possible an acid soil for pupation. Almost all districts found infested had alkaline or nearly neutral soils.

Both males and females have been found fertile after an adult life longer than the host-free period that was established in the Rio Grande Valley. The possible life cycle at 21° C. (70° F.) is estimated to be about 13 months. The adults are not dependent on the host fruits for food.

Copper chloride, copper nitrate, copper sulphate, and copper carbonate are toxic to the adults of *A. ludens*, the toxic action being apparently associated with the destruction of the yeasts and molds that may be a necessary part of their diet.

A. ludens can develop under a wide range of temperatures, whereas its parasite *Opius crawfordi* has a short range of optimum development which limits its effectiveness to favorable climates.

The parasite *O. crawfordi* is very decidedly affected by variations in atmospheric humidity. A humidity higher than 50 percent seems necessary for optimum development.

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WASHINGTON, D.C.

MARKET DISTRIBUTION OF CAR-LOT SHIPMENTS OF FRUITS AND VEGETABLES IN THE UNITED STATES

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INTRODUCTION

Approximately a million carloads of fruits and vegetables were shipped annually in the United States during the 10 years ended in 1931. In 1932 and 1933 car-lot shipments fell somewhat below the million mark. The distribution among the markets of these vast quantities of perishable-food products presents many problems. Loss from spoilage and deterioration is likely to result from delay in handling. Sharp price declines are frequently caused by rapid increases in market supplies. The fact that control of shipments is usually in the hands of a number of agencies acting independently adds to the difficulty of obtaining efficient distribution.

The purpose of this study is to analyze the available statistics on market distribution of car-lot shipments. The relative importance of markets is considered according to location, population, and commodity. The regularity of distribution to various markets, the distance of origin of supply from important markets, the relative importance of various commodities in the supply of different cities, and other pertinent phases are discussed.

Cooperative marketing associations and other shippers are constantly canvassing the possibilities of developing new market outlets and seeking means of obtaining a more effective distribution. Information of this kind should be helpful to these agencies in studying

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the available markets with a view to obtaining the most satisfactory market distribution of the crops in which they are interested.

In addition to car-lot shipments, immense quantities of fruits and vegetables are moved to market by motor truck. It was estimated that in 1929 from 12 to 16 percent of the fresh fruit and vegetable supplies moving a distance of more than 20 miles to market in the United States was hauled by truck. Since then motor-truck shipments have increased and in 1932, records of receipts in 10 large cities indicated that approximately one-third of the total fruit and vegetable supply in these markets, including nearby production, was moved by motor truck.

The motor-truck movement is particularly important from producing districts within 100 miles of large markets, but large quantities are trucked more than 100 miles. However, the great volume of fruits and vegetables that move distances of 500 miles or more to market is still hauled by rail. Even under the conditions of the last few years in the United States, it seems probable that roughly 75 percent of the fruit and vegetable shipments moving 20 miles or more to market, were hauled by rail or boat.

A large part of the fruit and vegetable movement from producing districts to small markets within trucking distance of large cities which formerly was shipped by rail direct is now shipped to the large markets by rail and distributed to the smaller markets by truck. Dealers in these small markets have found that there is considerable risk in purchasing a car lot of a commodity. It may require several days to sell the car-lot purchase and in the meantime the price in the nearby large market may drop sharply, thus forcing a reduction in price of the unsold portion of the car-lot shipment, because of competition of supplies trucked in from the large car-lot market. The use of the truck has probably resulted in a wider distribution of some fruits and vegetables among the villages and in rural districts.

Statistics on motor-truck shipments of fruits and vegetables are not available for most producing districts, and estimates of motor-truck receipts are available for only a limited number of markets. This study, therefore, deals largely with the analysis of car-lot shipment and unload data. Such information as is available on motor-truck movement is used in a supplemental way in explaining the statistics relating to car-lot distribution.

The 1931 car-lot shipments of 1,013,000 cars were 5 percent less than the 1929 shipments, and in 1930 also, the shipments were slightly less than in 1929. There was a pronounced decrease in car-lot shipments in 1932 and 1933 to 835,000 and 787,000 cars respectively. A part of this decrease in rail shipments in those 2 years was undoubtedly due to an increase in truck movement. For example, in New York City, rail and boat unloads in 1933 were 20 percent less than in 1931, whereas total unloads including rail, boat, and truck were only 15 percent less than in 1931.

This study is based chiefly on an analysis of shipment figures for 1930 and 1931, since these 2 years are presumed to be fairly representative of conditions during the last 5 years.

Imports of fruits and vegetables in 1931 amounted to 2 to 3 percent of the domestic car-lot shipments. Leading items in the im-

ports were grapefruit, tomatoes, and potatoes. Data on imports are excluded in this study when market receipts are compared with shipments.

The figures on car-lot shipments and unloads are from the records of the Bureau of Agricultural Economics. Domestic shipments by boat stated in car lots are included in the car-lot shipment statistics. The unload data used in the distribution analysis are chiefly on 16 important fruits and vegetables which comprised about 85 percent of the domestic car-lot rail and boat shipments of all fresh fruits and vegetables in both 1930 and 1931. The market-news price statistics of the Bureau of Agricultural Economics are used in a few instances to illustrate points regarding distribution.

LOCATION OF PRODUCING AREAS

Fresh fruits and vegetables for market are produced generally throughout the United States. Every State in 1930, originated car-lot shipments of one or more fruits or vegetables. A few States, however, contribute a large part of the total supply (table 1). Many of the important producing States are located at long distances from the leading markets.

TABLE 1.—*Car-lot shipments of fruits and vegetables, and percentage of total shipments by States, 1930*

State of origin	Shipments		State of origin	Shipments	
	Cars	*Percent*		*Cars*	*Percent*
Alabama	6,809	0.6	Nevada	629	0.1
Arizona	16,835	1.6	New Hampshire	846	.1
Arkansas	3,846	.4	New Jersey	11,796	1.1
California	305,897	29.0	New Mexico	854	.1
Colorado	35,563	3.4	New York	66,188	6.3
Connecticut	141	(1)	North Carolina	16,604	1.6
Delaware	3,234	.3	North Dakota	5,365	.5
Florida	95,189	9.0	Ohio	4,488	.4
Georgia	36,775	3.5	Oklahoma	3,572	.3
Idaho	32,449	3.1	Oregon	17,069	1.6
Illinois	5,728	.5	Pennsylvania	5,728	.5
Indiana	10,169	1.0	Rhode Island	2	(1)
Iowa	3,388	.3	South Carolina	17,438	1.7
Kansas	4,555	.4	South Dakota	840	.1
Kentucky	1,338	.1	Tennessee	8,978	.9
Louisiana	9,022	.9	Texas	53,727	5.1
Maine	58,298	5.5	Utah	3,912	.4
Maryland	7,872	.7	Vermont	712	.1
Massachusetts	4,098	.4	Virginia	43,776	4.2
Michigan	16,782	1.6	Washington	66,892	6.3
Minnesota	20,354	1.9	West Virginia	3,743	.4
Mississippi	6,504	.6	Wisconsin	19,088	1.8
Missouri	5,524	.5	Wyoming	2,211	.2
Montana	858	.1			
Nebraska	7,915	.8	Total	1,053,601	100.0

[1] Less than 0.05 percent.

LOCATION OF IMPORTANT MARKETS

The principal markets are in the northern part of the United States east of the Mississippi River. Slightly more than one-half of the population of the United States is in the region east of the Mississippi and north of the Ohio and Potomac Rivers. This region

includes many large cities and industrial centers that are consuming markets for immense supplies of fruits and vegetables.

The Middle Atlantic States, consisting of New York, New Jersey, and Pennsylvania, and including a population of 26,000,000, comprise the most important consuming region. The East North Central States of Ohio, Indiana, Illinois, Michigan, and Wisconsin with a population of 25,000,000 are second in importance as a consuming region.

Car-lot unload statistics of fruits and vegetables are not available for all markets so it is impossible to make a complete analysis of the market distribution of car-lot shipments. Car-lot unload reports of the Bureau of Agricultural Economics are available, however, for 66 markets throughout the country; reports of the Pennsylvania Department of Agriculture for unloads in three additional cities were used in the study (fig. 1). These markets include the larger cities, and have a total population of about 33,000,000. Including the metropolitan

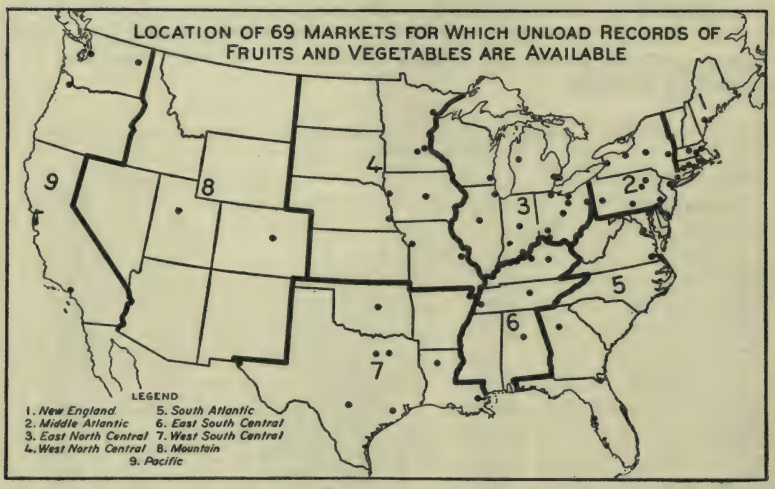

FIGURE 1.—These 69 markets, with a total metropolitan population of nearly 50,000,000, located in all nine geographic divisions, received about two-thirds of the United States car-lot shipments of 16 fruits and vegetables in 1930 and 1931.

population adjacent to these cities the population represented is about 49,000,000. The total population in places of 8,000 or more inhabitants in the United States, according to the 1930 census, was about 60,000,000.

Table 2 shows, by geographic divisions, the proportion of United States car-lot shipments of 16 fruits and vegetables which was unloaded in cities for which records were available in 1930. The car-lot unloads in 69 cities ranged from 49 percent of the United States car-lot shipments of apples to 90 percent of the grapefruit. For the 16 fruits and vegetables the ratio was 67 percent. Although this table does not present a complete picture of the geographical distribution of these commodities, it gives a fair idea of the relative importance of the various regions as consuming markets for car-lot shipments.

TABLE 2.—*Ratio of car-lot unloads, in 69 markets classified by geographical divisions, to United States car-lot shipments, 16 fruits and vegetables, 1930*

Commodity	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Apples	1.9	16.4	13.6	4.7	2.2	1.9	2.2	0.5	5.8	49.2
Cabbage	4.8	25.2	15.2	6.3	8.4	3.9	2.6	.4	.7	67.5
Cantaloups [1]	7.7	40.5	20.5	5.6	3.7	1.0	.8	1.0	5.0	85.8
Celery	5.8	33.6	18.2	7.6	6.8	1.9	3.4	.2	3.2	80.7
Grapefruit	7.8	31.9	22.0	7.2	11.0	2.3	2.5	1.2	4.4	90.3
Grapes	9.6	39.9	14.3	4.0	1.9	.7	1.3	.6	5.3	77.6
Lemons	5.2	20.5	20.4	8.6	4.7	3.3	6.3	1.4	4.6	75.0
Lettuce	5.8	30.5	20.0	7.1	5.0	2.0	4.3	1.4	4.7	80.8
Onions	7.9	27.7	16.5	5.0	5.2	2.4	4.2	.3	5.0	74.2
Oranges [2]	9.2	32.9	19.1	5.0	4.8	2.0	2.7	.9	3.8	80.4
Peaches [3]	5.0	28.6	20.8	7.0	3.2	1.1	1.5	.9	7.0	75.1
Potatoes	5.3	16.8	17.7	4.4	3.2	1.6	2.5	.4	5.4	57.3
Strawberries	10.5	24.2	27.9	6.4	1.5	.8	1.0	1.1	1.2	74.6
Sweetpotatoes	6.8	20.0	24.4	4.4	7.1	1.8	3.2	1.2	4.6	73.5
Tomatoes	7.6	31.8	15.8	3.8	6.0	2.2	2.8	1.0	2.1	73.1
Watermelons	2.5	14.7	16.9	6.0	6.2	3.9	2.4	.8	5.8	59.2
Average	5.8	24.4	17.5	5.2	4.2	1.9	2.6	.7	4.8	67.1

[1] Includes casaba, Honey Ball, Honey Dew, and Persian melons, etc.
[2] Includes satsumas and tangerines.
[3] Percentages are based on peach shipments of 24,291 cars; this excludes shipments to canneries.

Considering briefly the geographic distribution of car-lot shipments of certain commodities, we find that the most important apple markets are in the Middle Atlantic and East North Central States where the recorded unloads were 16 and 14 percent respectively of the Nation's car-lot shipments. Forty percent of the car-lot shipments of cantaloups were recorded as unloads in cities in the Middle Atlantic States and 20 percent in the East North Central States. Grapes also show a high percentage of the shipments unloaded in the Middle Atlantic States.

Strawberries are trucked to market in large quantities from important producing sections serving the Middle Atlantic markets and the East North Central group of States is slightly more important as a consuming region for car-lot shipments of strawberries than is the Middle Atlantic region.

The development of the fruit and vegetable industries in the leading producing States—as California, Florida, Texas, and Washington—has been possible because transportation and refrigeration facilities permitted the shipment of these perishable products long distances to the important markets in the northeastern section of the United States.

The estimated average distances from market of the origin of car-lot shipments of 19 fruits and vegetables unloaded in New York City in 1930 are shown in table 3. Since the car-lot unloads in New York constituted more than 85 percent of the fruit and vegetable supply on the New York City jobbing markets in 1931, this distance of more than 1,400 miles as the average car-lot haul for fruits and vegetables to the New York market indicates the large extent to which the metropolis is dependent on distant producing areas for its food supply. Similar conditions apply in many other important markets in the northeastern part of the country.

TABLE 3.—*Average distance of origin of car-lot unloads of 19 fruits and vegetables at New York, 1930*

Commodity	Estimated average distance	Commodity	Estimated average distance
	Miles		*Miles*
Apples	1,321	Peaches	915
Cabbage	571	Pears	2,303
Cantaloups	2,369	Plums	2,293
Celery	1,102	Potatoes	399
Grapefruit	1,012	Strawberries	871
Grapes	2,414	Sweetpotatoes	424
Lemons	2,500	Tangerines	1,000
Lettuce	1,814	Tomatoes	1,262
Onions	904	Watermelons	793
Oranges	1,873	Average	[1] 1,436

[1] Average weighted according to number of cars of each commodity unloaded in New York.

FLUCTUATIONS IN DAILY MARKET SUPPLIES AS MEASURED BY PRICE

Under the present system of marketing, the control of shipments of fruits and vegetables in most instances is divided among a number of shippers which makes it very difficult to obtain the best possible distribution among the various markets. The shippers may be cooperative associations, national marketing agencies, local dealers, or city dealers usually acting independently of each other. The market-news facilities with information on number of car-lot shipments, destinations in some instances, market supply, and price data, are of assistance in the distribution of fruits and vegetables, but without centralized control of shipments it would not be expected that the most efficient distribution would result.

Much has been written concerning market gluts and irregularities in the distribution of fruits and vegetables. There are many instances during a season in which it apparently would be possible to have a more even flow of a product to market, and to regulate the supply so as to obtain more satisfactory returns to the shippers, if there were centralized control of a large part of the shipments of the commodity. On the whole, however, variations in supply on the markets from day to day are not so great as might be expected.

It is extremely difficult to obtain exact figures on the supply from day to day because of quantities held over by wholesalers and retailers, and because of motor-truck receipts. The jobbing prices on the markets are general indicators of the fluctuations in supply from day to day, assuming that the demand remains fairly constant. This is particularly true of the more perishable commodities, such as peaches and strawberries.

Tables 4 and 5 show the daily averages of market-news prices of Georgia peaches and Louisiana strawberries in certain markets during the principal part of the 1931 season. For peaches, the changes from one daily price to the next varied from 0 to 30 cents per bushel. In Pittsburgh, the price rose from $1.12 per bushel on August 7 to $1.42 on August 8, a 27-percent change (table 4). The average change was approximately 9 percent.

TABLE 4.—*Daily price per bushel to jobbers for Georgia Elberta peaches, specified markets, July 23 to August 10, 1931* [1]

Date	New York	Philadelphia	Pittsburgh	Chicago	Date	New York	Philadelphia	Pittsburgh	Chicago
July 23	$1.44	$1.25	$1.52	$1.75	Aug. 1	$0.94	$0.80	----	$1.12
24	1.25	1.00	1.38	1.58	3	.94	.98	$1.08	1.18
25	1.25	----	1.50	1.58	4	----	1.12	1.02	1.18
27	1.18	1.20	1.32	1.48	5	1.12	1.08	1.08	----
28	1.18	1.10	1.32	1.38	6	1.06	1.08	1.12	1.38
29	1.00	1.12	1.12	1.12	7	1.12	.95	1.12	1.32
30	1.25	.88	1.12	1.25	8	1.18	----	1.42	1.32
31	1.00	----	1.25	1.12	10	1.24	1.00	1.28	1.38

[1] Grade U.S. No. 1, all sizes. When the original prices included a range, the mid point is shown in this tabulation.

Relative to this average price change from day to day, it should be kept in mind that there is usually an increase in supply as the season progresses and as various districts begin to ship. This results in a downward trend in price, which for the peach prices shown in table 4 would average a little more than 1 percent decline per day. It is also to be kept in mind that price changes are not an exact measure of supply changes, chiefly because of changes in factors of composition of supply as quality, condition, and size. The supply of competing products and other factors may change the demand somewhat from day to day but the daily changes in average price are a fair index to daily changes in supply.

TABLE 5.—*Daily price per 24-pint crate to jobbers for Louisiana strawberries, specified markets, April 6 to May 14, 1931* [1]

Date	Pittsburgh	Cleveland	Detroit	Chicago	Date	Pittsburgh	Cleveland	Detroit	Chicago
Apr. 6	$4.00	$4.12	$4.00	$3.62	Apr. 25	$3.38	$3.00	$3.25	$2.88
7	3.88	4.12	4.00	----	27	3.00	3.12	2.82	2.75
8	4.12	4.38	4.75	4.62	28	2.75	2.92	2.92	2.68
9	5.00	5.12	4.70	5.00	29	3.08	3.12	3.12	3.12
10	5.25	5.30	4.88	4.88	30	3.45	3.50	3.28	3.38
11	----	5.12	4.88	5.00	May 1	3.62	3.58	3.38	3.12
13	5.42	5.38	5.12	5.12	2	3.62	3.58	3.12	3.12
14	5.38	5.38	5.12	4.62	4	3.52	3.45	3.15	3.12
15	5.00	----	5.25	3.92	5	3.38	3.12	3.20	3.12
16	4.25	4.12	4.00	3.62	6	3.12	3.12	3.15	3.12
17	4.12	3.88	4.00	3.62	7	3.25	3.25	3.08	3.12
18	3.88	3.42	4.50	3.38	8	3.38	3.25	3.15	2.88
20	2.75	2.88	2.88	2.62	9	3.50	3.08	3.38	2.38
21	2.62	2.75	2.62	2.62	11	2.62	2.85	2.52	2.38
22	2.88	2.92	3.25	2.62	12	2.38	2.42	2.58	2.25
23	3.12	3.12	2.62	2.88	13	2.25	2.50	2.58	2.12
24	3.38	3.50	3.38	3.12	14	2.12	2.50	2.38	2.12

[1] Klondike strawberries, generally good quality and condition. When the original prices included a range, the mid point is shown in this table.

For strawberries, the average price change from one day to the next was 7 percent. The maximum change was 36 percent, which occurred in Detroit from Saturday, April 18, to Monday, April 20, when the average price dropped from $4.50 per crate to $2.88 (table 5). It will be noted that, for the period April 18 to 20, supplies increased greatly in Pittsburgh, Cleveland, Detroit, and Chicago as indicated by the sharp price decline. It is apparent, therefore, that there was a heavy supply of strawberries on most of the important markets

rather than an irregular supply among the markets. In many instances, price changes from day to day were in the same direction in the different markets indicating that general supplies for the markets were heavier or lighter rather than that one city had a heavy supply while another had a light supply.

Observations of price changes from day to day in important markets for other commodities—as tomatoes, lettuce, and celery—indicate fluctuations in price and supply generally similar to those for strawberries and peaches shown in tables 4 and 5.

The conclusion from these observations of market price changes from day to day is that the flow of fruits and vegetables to the leading markets is fairly even considering the fact that in most instances the control of distribution is not centralized. There are, however, instances of sharp fluctuations in price and supply.

COMPARISON OF SEASON'S SUPPLIES IN VARIOUS MARKETS AS MEASURED BY PRICE

In a good distribution the average seasonal prices on different markets should be such that when transportation and other marketing charges are deducted the prices on a shipping-point basis would be about the same for shipments to the different markets. This is assuming that the average quality and condition of the shipments are approximately the same on the various markets.

The average of daily prices to jobbers during the 1931 season is shown for certain fruits and vegetables in specified markets in table 6. It appears that there is not usually a wide variation in the seasonal prices in different cities. For example, in the case of Florida celery, where the differences in transportation charges to the markets listed are small, the highest seasonal price among the seven markets was $3.42 in Chicago, which was only 5 percent above the lowest, $3.26 in Philadelphia.

TABLE 6.—*Average daily price to jobbers for specified fruits and vegetables in 7 markets, 1931*

Commodity and market period	Boston	New York	Philadelphia	Pittsburgh	Detroit	Chicago	St. Louis
California cantaloups, Standard 45's, May 18–July 11	$2.85	$2.89	$2.86	$2.80	$2.83	$2.58	$2.60
Florida celery, 10-inch crates, Jan. 26–Apr. 18	3.36	3.32	3.26	3.37	3.39	3.42	3.34
California lettuce, crates, 4 to 5 dozen, Jan. 2–Apr. 9	2.82	2.81	2.61	2.67	2.73	2.68	2.76
Georgia peaches, U.S. No. 1 Elberta, bushels, 2 to 2½ inches, July 20–Aug. 11	1.21	1.19	1.09	1.25	1.44	1.41	-------
Florida potatoes, U.S. No. 1 barrels, Spaulding Rose No. 4, Apr. 8–May 15	6.55	6.27	6.22	6.69	6.57	6.54	-------
Louisiana strawberries, 24-pint crates, Klondike, Mar. 30–May 25	3.60	3.36	3.12	3.41	3.33	3.14	3.27
Mississippi tomatoes, U.S. No. 1 flats, June 15–July 8	.67	.72	.77	.71	.66	.68	.79

For Georgia peaches in bushel baskets the seasonal price in Detroit and Chicago was considerably higher than in the eastern markets. This may be due in part to the fact that the crate is preferred as a package for peaches in the East, whereas the bushel basket is preferred in the Middle West.

For Florida potatoes the seasonal price ranged from $6.22 per barrel in Philadelphia to $6.69 in Pittsburgh, an increase of 8 percent over the Philadelphia price.

On the whole it appears that the distribution of a commodity from a certain producing area is usually such that the seasonal price received by the shippers is not greatly different for the various markets.

COMPARISON OF VARIOUS METROPOLITAN DISTRICTS AS CAR-LOT MARKETS

The consuming capacity of any market is influenced by a number of factors among which may be mentioned the size of the city itself and of the metropolitan area of which it is the center, the extent to which the area outside of the metropolitan district draws on the market for supplies, the food habits of the population as determined by racial or other characteristics, the degree of prosperity, the changes in volume and location of production from year to year, and the trade methods and practices.

In a study of the market distribution of fruits and vegetables, it is essential to know what part of the domestic car-lot shipments of each commodity is unloaded in each of the leading markets and how much this is likely to vary from year to year. A comparison of the percentages of shipments of different commodities unloaded in any market is significant. The importance of the various markets can also be studied according to populations.

In table 7 is shown for 1930 and 1931 the percentages of United States car-lot shipments of 16 commodities unloaded in markets classified according to size of metropolitan districts. The metropolitan population figures are those shown in the 1930 census and include the population surrounding a city which is largely influenced economically and socially by the city. All metropolitan districts listed in table 7 have populations of 100,000 or more.

A comparison of the percentages of car-lot shipments unloaded in the specified markets in 1930 and 1931 shows remarkably small differences. This is true even though the car-lot shipments of some commodities as grapefruit, grapes, oranges, and peaches varied widely between the 2 years.

The population in the 61 market districts in 1930 was equal to about 72 percent of the urban population in places of 2,500 or more, and 40 percent of the total population.

The relation of unloads to shipments for each commodity and each market and group of markets with few exceptions shows a high degree of similarity for the 2 years. Although the grape shipments dropped from 70,890 cars in 1930 to slightly less than 47,000 in 1931, the percentages of total shipments unloaded in the 61 market districts were 77.2 and 79.7 respectively for the 2 years. For oranges, although the shipments increased from 65,923 in 1930 to more than 95,000 in 1931, the proportion of shipments unloaded in the 61 market districts dropped only 2.3 percent from 79.5 percent in 1930 to 77.2 percent in 1931.

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TABLE 7.—*Percentage of United States car-lot shipments of 16 commodities unloaded in markets classified according to size of metropolitan districts, 1930 and 1931*

1930

Market[1]	Apples	Cabbage	Cantaloups[2]	Celery	Grapefruit	Grapes	Lemons	Lettuce	Onions	Oranges[3]	Peaches[4]	Potatoes	Strawberries	Sweetpotatoes	Tomatoes	Watermelons	16 commodities
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Boston	1.2	3.0	5.5	3.6	5.1	6.2	3.9	3.7	5.2	6.0	3.3	3.1	6.6	4.2	4.9	1.2	3.6
Chicago	5.5	4.8	8.9	7.1	9.1	6.8	7.8	8.7	5.7	7.5	6.6	6.4	9.9	8.6	6.7	4.8	6.7
Cleveland	1.3	1.7	3.0	1.7	2.8	1.5	2.6	2.0	2.1	2.5	2.2	1.6	3.0	2.9	.5	1.8	1.8
Detroit	1.9	2.1	3.2	3.1	3.2	2.0	2.7	3.1	3.6	3.1	3.1	3.2	4.8	3.7	3.1	2.6	2.9
Los Angeles	3.7	.0	1.4	.3	.6	2.1	.0	2.2	1.5	.3	2.7	2.6	.0	1.6	.1	3.6	1.9
New York-northeastern New Jersey[5]	10.8	13.4	25.9	19.2	18.3	27.2	10.5	18.7	16.0	19.5	18.8	9.6	12.9	8.9	19.5	7.0	14.6
Philadelphia	2.3	6.0	6.6	6.8	6.2	5.3	4.2	6.0	5.9	6.3	4.1	3.3	3.4	1.7	5.6	3.5	4.4
Pittsburgh	2.6	3.5	3.9	3.8	3.0	4.1	2.9	2.7	2.9	3.0	3.0	1.8	2.9	5.0	4.0	1.9	2.7
St. Louis	1.0	3.3	2.4	2.6	2.4	1.1	3.2	2.9	2.4	1.8	2.1	1.9	1.4	1.5	1.3	2.7	2.0
San Francisco	.8	.0	1.6	1.6	1.7	4.0	2.6	.6	1.7	1.6	2.1	1.4	.0	.8	1.0	.6	1.4
Total[1]	31.1	37.8	62.4	49.8	52.4	58.3	40.4	50.6	47.0	51.6	48.0	34.9	44.9	38.9	46.7	29.7	42.0
Baltimore	.5	3.9	1.6	2.9	2.7	.9	2.6	1.8	1.8	2.1	1.6	1.2	1.0	4.5	3.0	1.7	1.7
Buffalo-Niagara	.2	.7	1.4	1.6	1.6	1.0	1.1	1.2	.8	1.4	.8	.5	2.4	1.6	.8	.7	.8
Cincinnati	1.3	2.0	2.0	1.5	1.8	.8	2.8	1.3	1.4	1.5	2.8	1.4	2.9	2.9	1.3	2.4	1.6
Kansas City, Mo., and Kansas City, Kans	1.0	1.1	1.2	1.5	1.5	.8	1.7	1.4	1.0	.8	.8	1.0	.9	.6	.8	1.2	1.0
Milwaukee	1.0	.5	.8	1.4	.9	1.3	1.0	.9	.6	1.0	1.5	1.0	1.8	.3	.6	.7	1.0
Minneapolis and St. Paul	1.3	.6	1.0	2.0	1.7	1.2	1.9	1.4	.5	1.3	2.2	.4	2.3	1.2	.9	1.0	1.0
Providence, R.I., Fall River, and New Bedford, Mass.[6]	.1	.6	.6	.6	.4	.6	.3	.5	.8	.7	.4	.5	1.1	.5	.9	.3	.5
Scranton and Wilkes Barre[7]	.3	.6	.7	.9	.7	.9	.3	.6	1.1	.8	.6	.6	.3	.9	.9	.4	.6
Washington, D.C.	.3	1.6	1.2	1.6	1.9	.4	.3	1.3	1.0	1.1	.8	.7	.3	1.4	1.1	1.1	.9
Total[1]	6.0	11.6	10.5	14.0	13.2	7.9	12.0	10.4	9.0	10.7	11.5	7.3	13.0	13.9	10.3	9.5	9.1
42 districts[1]	11.2	17.0	12.3	16.0	23.3	11.0	21.6	19.0	16.9	17.2	14.7	14.2	15.1	19.5	14.6	19.2	15.1
61 districts[1]	48.3	66.4	85.2	79.8	88.9	77.2	74.0	80.0	72.9	79.5	74.2	56.4	73.0	72.3	71.6	58.4	66.2
Car-lot shipments	*Cars* 107,033	*Cars* 38,205	*Cars* 36,179	*Cars* 26,411	*Cars* 20,001	*Cars* 70,890	*Cars* 14,274	*Cars* 55,628	*Cars* 39,577	*Cars* 65,923	*Cars* 24,291	*Cars* 252,411	*Cars* 10,578	*Cars* 19,045	*Cars* 34,050	*Cars* 59,011	*Cars* 873,507

	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Boston	1.8	3.6	5.4	3.7	5.1	6.9	3.5	3.9	5.5	5.9	3.9	2.9	6.0	5.4	5.7	1.3	3.9
Chicago	6.3	5.1	8.1	6.9	7.2	6.8	6.8	8.7	5.6	6.6	7.6	6.8	9.5	10.2	7.8	5.4	6.9
Cleveland	1.1	1.5	2.9	1.8	2.7	1.1	2.2	2.2	1.8	2.3	2.3	1.6	3.0	4.1	.5	2.1	1.8
Detroit	2.3	2.3	3.1	3.7	3.7	1.9	2.8	3.1	2.5	3.0	4.3	2.7	4.8	4.8	3.4	2.6	2.9
Los Angeles	3.7	.4	1.0	.4	.5	.1	.0	1.7	2.5	.1	1.8	2.7	.0	1.3	.1	3.8	1.8
New York-northeastern New Jersey [5]	12.9	17.0	25.2	20.7	18.8	28.4	13.5	19.1	19.9	20.2	16.9	9.2	14.1	7.3	19.9	7.7	15.3
Philadelphia	2.4	7.5	6.3	7.3	5.4	5.6	4.5	6.4	6.3	5.8	3.2	2.6	3.1	1.2	5.5	3.2	4.2
Pittsburgh	2.1	3.1	4.2	3.9	2.5	3.7	2.8	2.5	2.8	2.5	2.5	1.7	2.8	5.6	4.2	1.6	2.5
St. Louis	.6	3.9	2.2	2.5	2.2	1.2	2.7	2.7	2.5	1.8	1.2	1.9	2.1	1.0	2.2	3.3	2.0
San Francisco	.7	.0	1.4	1.5	1.4	4.4	1.9	.6	2.7	1.2	1.1	1.5	.0	.2	.4	.8	1.3
Total [1]	33.9	44.4	59.8	52.4	49.5	60.1	40.7	50.9	52.1	49.4	44.8	33.6	45.4	41.1	49.7	31.8	42.6
Baltimore	.4	3.8	1.7	3.2	2.0	1.0	2.8	1.7	1.8	1.9	.8	1.2	1.1	3.6	3.2	2.7	1.6
Buffalo-Niagara	.2	.7	1.1	1.6	1.6	.9	1.2	1.2	.6	1.4	1.2	.5	2.2	2.2	.8	.8	.9
Cincinnati	1.0	1.7	1.8	1.7	1.7	.9	2.4	1.3	1.3	1.5	2.2	1.3	3.5	3.3	1.4	2.9	1.6
Kansas City, Mo., and Kansas City, Kans	.9	1.2	1.3	1.5	1.6	.6	1.2	1.4	1.1	.8	1.0	1.1	1.3	.4	1.1	1.5	1.1
Milwaukee	1.6	.5	.8	1.6	1.0	1.6	.7	1.0	.5	1.0	2.3	1.0	1.9	.5	.7	.9	1.1
Minneapolis and St. Paul	1.2	.9	1.3	2.6	2.1	1.2	1.5	1.6	.8	1.3	1.8	.7	2.5	1.5	1.2	1.0	1.2
Providence, R. I., Fall River, and New Bedford, Mass. [6]	.3	.8	.8	.5	.4	.8	.3	.6	.9	.7	.8	.5	1.2	.7	1.0	.4	.6
Scranton-Wilkes Barre [7]	.3	.7	.7	.7	.7	.8	.3	.5	1.0	.8	.8	.5	.4	.9	.9	.4	.6
Washington, D.C	.3	1.5	1.3	1.8	1.5	.6	.1	1.4	1.1	1.1	.6	.9	.4	1.3	1.0	1.4	.9
Total [1]	6.2	11.8	10.8	15.2	12.6	8.4	10.5	10.7	9.1	10.5	11.5	7.7	14.5	14.4	11.3	12.0	9.6
42 districts [1]	10.9	16.2	13.5	15.5	22.4	11.2	18.5	19.3	16.2	17.3	13.7	14.3	14.9	19.6	15.1	18.5	15.3
61 districts [1]	51.0	72.4	84.1	83.1	84.5	79.7	69.7	80.9	77.4	77.2	70.0	55.6	74.8	75.1	76.1	62.3	67.5
Car-lot shipments [8]	Cars 98,348	Cars 38,668	Cars 36,567	Cars 22,475	Cars 28,995	Cars 46,895	Cars 18,253	Cars 49,878	Cars 33,772	Cars 95,331	Cars 37,963	Cars 240,624	Cars 13,767	Cars 16,131	Cars 27,654	Cars 52,066	Cars 857,387

[1] The total metropolitan populations of the various groups of districts according to the 1930 census were: for 10 districts of 1,000,000 or more population, 30,576,781; for 9 districts of 500,000 to 1,000,000, 6,950, 199; for 42 districts (listed in table 9) of 100,000 to 500,000, 11,853,450; total for 61 districts, 49,380,430.

[2] Includes casaba, Honey Dew, Honey Ball, Persian, etc.

[3] Satsumas and tangerines included.

[4] Intrastate shipments of California peaches, except those going to Los Angeles and San Francisco, were subtracted from the total United States peach shipments to obtain the figure (24,291) used in this computation as fresh-peach shipments for 1930, and 37,963 for 1931.

[5] Includes Newark, N.J.

[6] Unloads included are for Providence only.

[7] Unload reports from records of the Pennsylvania Department of Agriculture.

[8] Shipment and unload figures for 1931 are subject to revision.

The figures in table 7 indicate that there was a fairly even distribution among the markets of the total season's car-lot shipments of a commodity even though the number of cars shipped varied considerably in different years. In case of a small crop, however, there appears to be some tendency for a slightly higher percentage of shipments to go to the larger markets.

In view of the general similarity of the percentages for the 2 years, only the 1930 figures are used in the discussion in the following paragraphs.

In the group of 10 largest markets in 1930, the ratio of unloads to United States shipments in round numbers ranged from 30 percent for watermelons to 62 percent for cantaloups. In the next size group of 9 markets the range was from 6 percent for apples to 14 percent for celery, whereas in the group of 42 smaller markets the range was from 11 percent for grapes and apples to 23 percent for grapefruit. For the entire 61 marketing districts represented, the lowest ratio of unloads to shipments was for apples with 48 percent, and the highest was grapefruit with 89 percent. It is possible that this figure for grapefruit is slightly high as the reports of grapefruit unloads in some markets may have included some cars of mixed citrus fruit.

The fact that the percentage of apples unloaded in the 61 market districts is relatively low is explained by the comparatively wide distribution of apples including considerable shipments to the smaller markets and by the fact that large quantities of the apple shipments were exported.

Only 56 percent of the potato shipments were unloaded in 1930 in the 61 markets. This indicates that potatoes, which are a widely used commodity and are less perishable than many other vegetables and which take a lower freight rate than most others, are distributed in car lots to the smaller markets of less than 100,000 population to a greater extent than are most other fruits and vegetables.

Watermelons, too, are widely distributed among the smaller markets in car lots, since only 58 percent of the 1930 car-lot shipments were unloaded in the 61 metropolitan districts. The market-news reports showed shipments of southeastern watermelons to 426 destinations in 1930 and 418 in 1931. These destinations include important diversion points so that the number of markets at which shipments were actually unloaded was much greater than the number of original destinations.

The 61 markets received approximately 80 percent or more of the 1930 car-lot shipments of cantaloups, celery, grapefruit, lettuce, and oranges (table 7). These commodities which apparently did not have as wide a car-lot distribution as the others are among those of a more perishable nature.

Interesting facts as to the comparative importance of various markets are brought out by table 7. The New York-northeastern New Jersey metropolitan district, including unloads at New York and Newark, is by far the most important market and it absorbs immense quantities of fruits and vegetables. It received about 15 percent of the combined car-lot shipments of 16 fruits and vegetables. This district received 27 percent of the grape shipments in 1930, 26 percent of the cantaloup shipments, and about 19 percent each of the celery, lettuce, orange, peach, and tomato shipments, as compared with only

7 percent of the watermelon shipments, 9 percent of the sweetpotatoes, 10 percent of the potatoes, and 11 percent of the apples.

Chicago is the second city in importance as a car-lot market and unloaded about 7 percent of the shipments in 1930. Ten percent of the strawberry shipments were unloaded in Chicago, and 9 percent of the cantaloup, grapefruit, lettuce, and sweetpotato shipments compared with only 5 percent of the cabbage and watermelon shipments in 1930.

Other cities show variations in percentages of shipments unloaded, which can usually be explained in a general way by local marketing conditions. For example, heavy motor-truck receipts frequently explain why car-lot receipts are small. Motor-truck receipts of 16 fruits and vegetables in 1931 in 8 markets for which statistics are available are shown in table 8 and are important in the supply in most of these markets. The car-lot unloads of many commodities in Los Angeles were very small because a large part of the supply (58 percent of the domestic supply of 16 products in 1930 and 62 percent in 1931) was brought in by truck from producing areas. For apples, potatoes, and watermelons, however, the Los Angeles unloads are relatively as large as in most other markets. San Francisco, too, had small unloads of most commodities partly because of heavy truck receipts, and because car-lot unloads at Oakland are not included in the statistics.

TABLE 8.—*Motor-truck receipts of 16 fruits and vegetables in 8 markets, 1931*

Commodity	Boston	Denver	Kansas City, Mo.	Los Angeles	New York [1]	Philadelphia	Salt Lake City	San Francisco
	Cars	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*
Apples	1,568	17	59	266	2,300	1,853	124	373
Cabbage	509	97	59	1,099	1,771	691	76	322
Cantaloups [2]	2	173	61	2,331	829	1,173	204	496
Celery	388	160	-------	2,469	742	265	94	399
Grapefruit	13	-------	-------	1,003	-------	-------	2	24
Grapes	35	-------	11	1,455	205	222	26	325
Lemons	-------	-------	-------	612	-------	-------	29	40
Lettuce	1,054	206	36	3,415	1,214	412	110	1,300
Onions	83	62	14	565	1,519	212	85	49
Oranges	-------	-------	-------	3,735	-------	1	54	293
Peaches	25	-------	18	1,446	1,833	1,824	126	354
Potatoes	99	499	205	1,870	4,579	3,571	574	269
Strawberries	160	46	38	628	600	1,083	68	286
Sweetpotatoes	-------	-------	43	625	1,647	1,879	1	149
Tomatoes	376	109	141	2,755	1,917	1,474	225	667
Watermelons	-------	17	1	763	17	328	66	23
Total	4,312	1,386	686	25,037	19,182	14,988	1,864	5,369
Relation of truck receipts to total domestic car-lot and truck receipts	*Percent* 12	*Percent* 20	*Percent* 7	*Percent* 62	*Percent* 14	*Percent* 29	*Percent* 58	*Percent* 32

[1] Motor-truck receipts at Washington Street wholesale market and Wallabout and Gansevoort farmers' markets.

[2] Includes casaba, Honey Dew, Honey Ball, etc.

The low figure of less than 2 percent as the ratio of sweetpotato unloads in Philadelphia to United States car-lot shipments may be explained by the fact that Philadelphia is within easy trucking distance of important sweetpotato-producing districts. In 1930, about 73 percent of the Philadelphia sweetpotato receipts were brought in by truck.

It is apparent that the importance of any city or group of cities as a consuming market for car-lot shipments varies widely when different commodities are considered.

UNLOADS PER 100,000 POPULATION IN VARIOUS MARKETS AND GROUPS OF MARKETS

As a method of comparing various markets in regard to their consumption of domestic car-lot and boat shipments of fruits and vegetables, the unloads of 16 commodities per 100,000 metropolitan population have been computed for 61 metropolitan districts for 1930 (table 9). The year 1930 was fairly representative of the years 1926 to 1931 in regard to fruit and vegetable shipments. For the 16 commodities under consideration in 1930 shipments were about 3 percent greater than in 1931. The consumption of any commodity, of course, varies somewhat from year to year according to total production.

The metropolitan districts have been grouped according to size including 10 districts of 1,000,000 or more population, 9 districts of 500,000 to 1,000,000, and 42 districts of 100,000 to 500,000 population.

In studying table 9, showing unloads per 100,000 population in various metropolitan districts, it should be kept in mind that in most instances these domestic unloads cannot be considered as consumption figures since some of the unloads were distributed by truck to points outside the metropolitan districts. For some commodities and some markets this outward movement of car-lot receipts may be partly, or more than, offset by motor-truck receipts from producing areas or in some cases by imports. Some of the smaller metropolitan districts are near enough to the larger cities to receive supplies from them by truck. Moreover, there are a few car-lot unloads within some metropolitan districts, for which statistics are not available. For example, unload statistics for the San Francisco district do not include unloads at Oakland; for the Albany-Schenectady-Troy district, only the unloads at Albany are available; and for the Providence-Fall River-New Bedford district, only the unloads at Providence are available. The table has value, however, in presenting certain general information relating to car-lot distribution.

The total car-lot and boat unloads of domestic shipments of 16 commodities per 100,000 population were not greatly different in the three groups of cities in 1930. For the group of largest cities the figure was 1,200 cars; for the next group 1,138 cars, and for the group of smaller cities 1,119 cars (table 9). When commodities are considered separately, there are some considerable variations in the different groups of cities.

The question as to whether the larger cities are relatively better markets than the smaller cities for certain commodities is answered in a general way through a study of table 9. As an illustration, the unloads of cantaloups and grapes averaged considerably greater per 100,000 population in the markets of more than 1,000,000 population than in the smaller markets. In the 10 metropolitan districts of more than 1,000,000 population the unloads of cantaloups per 100,000 population were 74 cars, compared with 55 in the 9 districts of 500,000 to 1,000,000 population, and 38 in 42 districts of 100,000 to 500,000 population. For grapes, the corresponding figures were 135, 80, and 66 cars.

Only very general conclusions can be drawn from such a comparison of unloads in different groups of markets, because wide differences appear when specific cities within any group are compared with respect to the unloads of certain commodities. These differences

can usually be explained in a general way by such factors as local production conditions, local distribution conditions, imports, or, for a few cities incomplete unload reports. For example, car-lot unloads of many commodities in Los Angeles as previously pointed out were very small because of nearness to producing districts.

A method of comparing unloads in cities of different sizes is to select certain markets within a size group, where truck receipts of the commodity are small, and make a comparison with markets selected on a similar basis in another size group. A straight average of the grape car-lot unloads per 100,000 population in Boston, Chicago, New York-northeastern New Jersey, Philadelphia, and Pittsburgh in 1930 is 151 cars. This compares with an average of 68 cars in the smaller markets of Columbus, Grand Rapids, Harrisburg, Hartford, and Syracuse.

A comparison of individual cities, where industrial conditions and racial characteristics differ, shows significant differences in the unloads of certain commodities per unit of population. The metropolitan populations of Columbus and Youngstown are not greatly different in size, yet in the latter city, which is largely industrial, grape unloads were 125 cars per 100,000 population in 1930 compared with 59 cars in Columbus. On the other hand celery unloads were only 10 cars per 100,000 population for the Youngstown district compared with 80 cars for Columbus. The smaller cities appear to be relatively better car-lot markets for watermelons, also southern cities are relatively better watermelon markets than northern cities.

Considering apples, one finds that in the group of largest markets, the unloads per 100,000 population varied from 54 cars in Boston, where important sources of apple supplies are near, to 173 cars in Los Angeles where sources are remote. The average for the group was 109 cars. In the group of 9 markets of 500,000 to 1,000,000 population, the apple unloads ranged from 17 cars per 100,000 in the Providence-Fall River-New Bedford district to 181 cars in the Cincinnati district with an average of 92. In the group of 42 smaller markets of 100,000 to 500,000 metropolitan population, the range in apple unloads per 100,000 was from 5 cars in Salt Lake City and Worcester, Mass., to 260 in Duluth with an average of 102 cars. It is evident, therefore, that extremely wide variations occur when various cities are compared as to their car-lot apple unloads per unit of population. The same is true for other commodities. It is difficult to account for some of these differences whereas others can be explained readily.

The apple unloads of 27 cars per 100,000 population in the Buffalo-Niagara metropolitan district were much smaller than at Cincinnati where they were 181 cars per 100,000. The chief reasons for this difference is that large quantities of apples are hauled by truck to the Buffalo-Niagara district, from the western New York apple-producing area, and that there is a considerable area surrounding Cincinnati which draws on that city for supplies.

In certain cities, as for example, Indianapolis and Columbus, where conditions may be considered somewhat similar, one would expect car-lot unloads of the different commodities per 100,000 population to be about the same, and in fact for most commodities this is true.

TABLE 9.—*Unloads of domestic car-lot and boat shipments, 16 fruits and vegetables, per 100,000 population in 61 metropolitan districts, 1930*

Metropolitan district	Apples	Cabbage	Cantaloups [1]	Celery	Grapefruit [2]	Grapes	Lemons	Lettuce	Onions	Oranges [2]	Peaches	Potatoes	Strawberries	Sweetpotatoes	Tomatoes	Watermelons	Total unloads per 100,000 population
	Cars	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*
Boston	54	50	87	41	44	191	24	90	89	171	35	337	30	34	72	31	1,380
Chicago	135	42	73	43	42	111	25	111	51	113	36	374	24	37	53	65	1,335
Cleveland	116	53	92	37	46	88	31	94	71	139	45	327	26	47	15	90	1,317
Detroit	98	37	54	39	30	69	18	81	68	97	35	379	24	33	51	73	1,186
Los Angeles	173	1	21	3	5	4	0	52	26	9	28	282	0	13	1	92	710
New York-northeastern New Jersey [3]	106	47	86	47	34	177	14	95	58	118	42	222	13	15	61	38	1,173
Philadelphia	85	81	85	63	44	131	21	118	82	145	35	293	13	11	66	71	1,344
Pittsburgh	143	68	72	51	31	146	21	76	58	100	38	235	16	49	69	57	1,230
St. Louis	84	98	67	52	38	61	36	126	71	94	39	376	11	22	34	121	1,330
San Francisco [4]	65	0	45	33	27	218	28	25	52	82	40	280	0	13	27	30	965
Total	109	47	74	43	34	135	19	92	61	111	38	288	16	24	52	57	1,200
Baltimore	60	156	63	80	57	69	40	105	73	145	40	323	11	90	109	104	1,525
Buffalo and Niagara, N.Y.	27	33	63	51	38	83	19	81	41	110	25	150	31	37	32	50	871
Cincinnati	181	101	93	52	48	77	53	94	72	128	89	453	40	73	60	189	1,803
Kansas City, Mo. and Kansas City, Kans.	174	67	74	66	48	96	39	125	68	91	31	428	15	19	43	117	1,501
Milwaukee	140	24	37	50	25	121	20	70	31	91	48	341	25	7	30	60	1,120
Minneapolis-St. Paul	167	30	44	65	41	99	32	97	23	104	64	116	29	28	35	68	1,042
Providence, R.I., Fall River, and New Bedford, Mass. [5]	17	22	21	18	9	46	4	28	32	49	10	127	12	9	33	21	458
Scranton and Wilkes-Barre [6]	46	38	37	36	20	96	8	49	68	79	23	230	6	27	45	36	844
Washington, D.C.	52	96	70	66	61	46	7	117	66	117	32	304	6	43	61	102	1,246
Total	92	64	55	53	38	80	25	83	52	101	40	265	20	38	51	81	1,138
Akron, Ohio	86	28	28	13	7	54	2	46	29	23	32	253	12	25	16	87	741
Albany, Schenectady, and Troy, N.Y. [7]	23	24	53	20	21	61	11	57	40	79	31	266	17	25	33	31	792
Atlanta	126	66	28	56	32	34	54	85	71	112	2	261	1	38	60	299	1,325
Birmingham	92	88	11	23	17	26	31	62	60	85	7	188	1	19	37	128	875
Bridgeport	45	38	37	23	22	113	15	48	38	110	32	291	10	18	29	41	910
Columbus	165	89	76	80	48	59	29	120	75	127	80	492	35	96	31	122	1,724
Dallas	164	57	8	43	37	42	47	142	82	97	5	357	8	54	73	60	1,276
Dayton	166	46	37	31	15	7	6	66	37	64	41	341	33	50	6	127	1,073
Denver	174	39	81	19	59	103	42	172	17	115	63	288	27	49	76	94	1,418
Des Moines	150	71	39	58	63	55	40	116	107	90	65	646	22	47	28	138	1,735
Duluth	260	38	35	44	24	86	17	75	62	78	42	94	22	13	55	49	994

El Paso	56	16	30	19	38	48	30	109	51	124	29	283	16	6	31	57	943
Evansville	76	183	20	53	40	28	33	89	98	137	31	564	15	8	[8] 309	162	1,846
Fort Worth	152	52	7	55	38	38	43	135	77	69	3	478	15	53	57	26	1,298
Grand Rapids	34	45	46	13	57	30	34	148	16	130	30	289	35	34	11	103	1,055
Harrisburg [6]	7	75	45	27	44	38	2	25	10	112	18	212	2	16	14	121	768
Hartford	30	17	31	20	29	90	10	38	15	92	11	76	10	21	23	16	529
Houston	118	33	6	41	27	55	51	107	84	86	31	363	0	42	43	77	1,164
Indianapolis	145	74	42	44	56	44	38	109	52	142	58	496	24	55	40	121	1,540
Jacksonville	160	106	30	66	[9] 579	38	0	115	144	107	36	303	0	0	69	310	2,063
Louisville, Ky	139	78	35	42	45	27	24	67	60	82	26	217	12	26	79	150	1,109
Memphis	134	154	33	48	41	53	55	114	95	121	13	383	2	12	42	157	1,457
Nashville	203	127	26	31	40	41	38	88	64	124	29	386	7	18	57	275	1,554
New Haven	60	46	37	28	32	288	4	107	73	119	29	286	10	37	61	34	1,251
New Orleans	66	72	36	44	15	43	43	100	112	87	23	219	0	2	41	146	1,049
Norfolk, Portsmouth, and Newport News, Va	77	98	12	39	18	20	4	50	56	79	9	147	2	6	22	42	681
Oklahoma City	176	89	10	60	35	37	37	141	70	104	13	370	12	6	52	44	1,256
Omaha, Nebr., and Council Bluffs, Iowa	222	73	56	53	47	104	39	105	44	103	69	413	31	29	46	106	1,540
Peoria, Ill	176	77	23	28	34	41	19	115	48	77	39	637	17	27	22	114	1,494
Portland, Oreg	126	21	79	27	42	91	25	116	45	133	46	208	15	47	34	98	1,153
Richmond	105	142	25	60	53	44	23	81	64	117	12	214	2	24	66	85	1,117
Rochester	11	21	52	33	40	122	25	80	27	120	19	137	19	34	22	64	826
Salt Lake City	5	13	57	0	29	55	35	123	31	123	2	72	13	31	41	94	724
San Antonio	122	11	3	53	5	56	49	119	58	73	20	288	2	54	40	11	964
Seattle	180	33	80	43	50	97	39	115	100	134	54	521	14	39	42	82	1,623
Spokane	54	20	73	34	31	54	30	116	77	110	112	360	9	47	30	154	1,311
Springfield and Holyoke, Mass	34	36	36	25	30	88	7	59	32	95	15	320	18	22	43	40	900
Syracuse	16	29	63	36	48	123	20	85	36	140	26	181	33	42	50	58	986
Tampa and St. Petersburg, Fla	164	76	41	40	76	64	0	137	100	12	46	424	0	11	66	113	1,370
Toledo	78	40	32	37	31	20	18	83	39	86	45	432	23	39	4	62	1,069
Worcester, Mass	5	5	9	7	0	19	1	1	14	11	2	289	6	4	7	16	396
Youngstown, Ohio	46	28	27	10	10	125	4	42	41	36	20	231	12	32	8	68	740
Total	102	55	38	36	40	66	26	90	56	96	30	302	13	31	42	96	1,119

[1] Includes Honey Dew, Honey Ball, casaba, and Persian melons.
[2] Only straight car-lot shipments of grapefruit or oranges were used in these computations. Mixed citrus shipments (mostly grapefruit and oranges) amounted to about 14 percent of the straight car shipments of oranges and grapefruit. Tangerines and satsumas are included with oranges.
[3] For this district, computations were based on unloads at New York City and Newark.
[4] For this district, computations were based on car-lot unloads at San Francisco. Reports on car-lot unloads at Oakland are not available.
[5] For this district, computations were based on unloads at Providence. Reports of car-lot unloads at Fall River and New Bedford are not available.
[6] Unload figures for these markets were obtained from reports of the Pennsylvania Department of Agriculture.
[7] For this district, computations are based on unloads at Albany. Reports of car-lot unloads at Schenectady and Troy are not available.
[8] Probably includes some tomatoes for manufacture.
[9] Includes a large quantity of fruit for reshipment from Jacksonville.

Unloads of many fruits and vegetables per 100,000 are not greatly different in Boston and Cleveland. The fact that the car-lot unloads of tomatoes are relatively much heavier in Boston may be explained by local production and distribution conditions. Ninety cars of watermelons per 100,000 population were unloaded in Cleveland compared with 31 cars in Boston. This wide difference is probably due chiefly to the consuming habits of the people and to differences in distances from producing districts.

For a commodity like cantaloups it would be expected that car-lot consumption in the large markets—such as Boston, Chicago, Cleveland, New York, Philadelphia, and Pittsburgh—would be proportionate to the metropolitan populations. The unloads of cantaloups within this group vary within a rather narrow range from 72 cars per 100,000 at Pittsburgh to 92 cars at Cleveland.

The consumption of domestic grapefruit and lemons was not so great per unit of population in the New York City district as in many other cities (table 9). This is explained in part, at least, by the fact that the consumption of imported grapefruit and lemons was large in New York. The figures for grapefruit, oranges, and lemons do not include that part of these commodities which arrived in mixed carloads.

Unloads of most commodities for the Providence-Fall River-New Bedford district were generally small. The unload information available for use in the computation was for Providence only. It is probable that considerable quantities of some commodities were unloaded at other points in the metropolitan district. There may also be some distribution to the district from Boston.

A comparison of the car-lot unloads of different commodities per 100,000 population in any city or group of cities shows wide variations which are in general relationship to the volume of car-lot shipments of the commodities. The unloads per 100,000 population in Philadelphia ranged from 11 cars of sweetpotatoes to 293 cars of potatoes. In St. Louis, the range was from 11 cars of strawberries to 376 cars of potatoes. In Oklahoma City, the range was from 6 cars of sweetpotatoes to 370 cars of potatoes.

A careful study of these figures in the light of supplemental knowledge as to local conditions in the various markets may assist distributors in determining which markets are most likely to show a favorable response to advertising or sales effort.

A complete analysis of the consuming capacities of various markets requires that receipts by truck as well as by other means be taken into consideration. In an effort to obtain data on total supplies of various fruits and vegetables in some markets, table 10 was prepared showing for representative markets for 3 years beginning with 1930 the total unloads including truck receipts of 16 products per 100,000 population. This information is shown for the five cities: Boston, New York, St. Louis, Denver, and Los Angeles, and supplements the data on car-lot unloads in table 9.

In computing the total unloads per 100,000 population in table 10, the populations of the metropolitan districts for the 1930 census were used except for New York where the city population of 6,930,000 was used because the Newark market is in the New York-northeastern New Jersey metropolitan district and truck receipts at Newark were not available in the Bureau records. Records of truck receipts are

probably only 75 to 95 percent complete, and records were not available for St. Louis in 1931.

It will be noted that for Boston the total annual supply of the 16 commodities for the 3 years shows but little variation ranging from 1,648 car-load units in 1930 to 1,684 in 1931, which is a change of approximately 2 percent. Los Angeles, too, shows only a small variation from year to year in the total supply. The other cities show wider variations. The fact that the New York figures are higher than those of the other markets is probably, partly at least, due to the fact that the New York metropolitan population is not used in the computation as explained in the preceding paragraph (table 10).

TABLE 10.—*Unloads of rail, truck, and boat shipments including imports of 16 fruits and vegetables, per 100,000 population in 5 representative markets for which truck unload reports are available 1930, 1931, and 1932 calendar years* [1]

Market and year	Apples	Cabbage	Cantaloups [2]	Celery	Grapefruit [3]	Grapes	Lemons	Lettuce	Onions
Boston:	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*
1930	124	76	87	57	50	196	25	131	96
1931	145	83	85	53	69	143	28	125	85
1932	156	71	78	51	47	145	23	125	91
New York:									
1930	194	115	139	104	94	244	62	174	130
1931	199	109	130	71	112	171	45	144	120
1932	185	115	118	73	76	190	41	139	111
St. Louis: [4]									
1930	130	106	70	52	41	62	36	126	73
1932	106	111	64	51	46	50	33	107	75
Denver:									
1930	184	69	117	76	62	103	42	233	54
1931	217	61	140	66	88	96	46	223	48
1932	185	61	109	69	79	91	39	217	41
Los Angeles:									
1930	181	52	113	123	31	94	21	180	55
1931	169	55	114	110	50	65	26	181	62
1932	172	57	106	123	44	85	20	185	48

Market and year	Oranges [3]	Peaches	Potatoes	Strawberries	Sweetpotatoes	Tomatoes	Watermelons	Total
Boston:	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*
1930	179	37	378	38	34	109	31	1,648
1931	251	65	346	44	38	94	30	1,684
1932	248	39	357	51	40	111	28	1,661
New York:								
1930	193	65	381	29	39	150	53	2,166
1931	294	106	360	36	40	124	53	2,114
1932	269	62	331	37	43	138	41	1,969
St. Louis: [4]								
1930	99	39	419	13	25	57	121	1,469
1932	141	35	377	25	24	90	81	1,416
Denver:								
1930	122	69	407	40	49	150	104	1,881
1931	184	136	455	51	49	132	122	2,114
1932	177	112	365	65	44	132	80	1,866
Los Angeles:								
1930	105	78	349	39	33	141	119	1,714
1931	168	91	358	31	36	137	118	1,771
1932	164	75	322	45	31	170	95	1,742

[1] Population figures used in computations in this table are 1930 census figures for metropolitan districts except for New York where the city population is used instead of New York-northeastern New Jersey district, because truck unloads for Newark are not available. Truck-receipt records are not complete, but probably represent 75 to 95 percent of the truck receipts on these markets.

[2] Includes Honey Dew, Honey Ball, casaba, and Persian melons.

[3] In this table car-lot unloads of mixed citrus were arbitrarily divided between grapefruit and oranges in the ratio of 1 to 3. Tangerines and satsumas are included with oranges.

[4] Information on truck receipts at St. Louis not available for 1931.

The annual supply of the 16 commodities per 100,000 population in the five markets ranged roughly from 1,500 to 2,100 cars. A figure of 1,800 cars per year at an assumed average weight per car of 28,000 pounds would amount to about 50,000,000 pounds. This is equal to approximately 1.4 pounds per capita per day of these 16 fruits and vegetables.

A comparison of the quantities of specific products unloaded in the five markets shows some wide variations. For each 100,000 inhabitants, Boston evidently consumes considerably more cabbage, grapes, and onions than Los Angeles but less cantaloups, celery, lettuce, tomatoes, and watermelons. The Los Angeles figures for supplies of oranges are surprisingly low as compared with some other cities. A possible explanation is that considerable quantities of oranges may be brought into Los Angeles in automobiles by consumers and consequently not included in the records of receipts. New York uses relatively more grapefruit and grapes than Boston but fewer strawberries.

For some commodities there are wide differences from year to year in the supply per unit of population for a certain city. This is probably chiefly due to variations in the volume and location of production.

A comparison of data for the five markets in table 10 with data for the same markets in table 9 shows that when truck receipts are inincluded the unloads per 100,000 population are changed materially for some commodities while for others which are not trucked in large quantities the figures in table 10 are approximately the same as in table 9. For example, in 1930 rail and boat unloads of apples per 100,000 population in Los Angeles were 173 cars as shown in table 9. When truck unloads were included the figure was raised only 8 cars to 181 as shown in table 10. For other commodities which are largely received by truck in Los Angeles, the figures for 1930 in table 10 are much greater than those in table 9. Most cities, however, do not receive as large a proportion of their supplies by truck as Los Angeles.

As a further aid to shippers in studying prospective markets, the populations of all metropolitan districts of 100,000 or more inhabitants as published in the 1930 Census are shown in table 11. This table includes a number of cities or metropolitan districts for which unload data are not available. Some of these districts are of much less importance as car-lot markets than would be indicated by their populations. This is because they are composed of rather densely populated industrial districts situated within easy trucking distance of other large car-lot markets. An example is the Allentown-Bethlehem-Easton district in Pennsylvania, which had a population in 1930 of about 322,000 but which is unimportant as a fruit and vegetable car-lot market except for a few commodities, as watermelons and potatoes. The reason is that this district is only about 50 miles from Philadelphia and about the same distance from the New York City metropolitan district.

Cooperative marketing associations and other shippers may find a study of the populations of metropolitan districts helpful in developing market outlets and obtaining an even distribution of their shipments.

VARIATIONS IN CAR-LOT DISTRIBUTION AMONG THE MARKETS FROM YEAR TO YEAR

The degree of regularity in the distribution of car-lot shipments of fruits and vegetables among the markets from year to year is indicated by the proportion of United States shipments of each commodity unloaded in each market annually over a period of years. The size of the United States production and its location, the quantity of local or nearby production which is marketed largely by truck, imports, competition from other crops, business conditions, and variations in the methods of marketing are factors that will influence the distribution among the various markets.

TABLE 11.—*Population of metropolitan districts of 100,000 or more population, classified by size groups, 1930*

Metropolitan district	Population	Metropolitan district	Population
Boston	2,307,897	Houston	339,216
Chicago	4,364,755	Huntington, W.Va., and Ashland, Ky.	163,367
Cleveland	1,194,989	Indianapolis	417,685
Detroit	2,104,764	Jacksonville	148,713
Los Angeles	2,318,526	Johnstown	147,611
New York-northeastern New Jersey	10,901,424	Knoxville	135,714
Philadelphia	2,847,148	Lancaster	123,156
Pittsburgh	1,953,668	Little Rock	113,137
St. Louis	1,293,516	Louisville	404,396
San Francisco	1,290,094	Lowell and Lawrence	332,028
		Memphis	276,126
Total	30,576,781	Miami	132,189
		Nashville	209,422
Baltimore	949,247	New Haven	293,724
Buffalo and Niagara, N.Y.	820,573	New Orleans	494,877
Cincinnati	759,464	Norfolk, Portsmouth, and Newport News	273,233
Kansas City, Kans., and Kansas City, Mo.	608,186	Oklahoma City	202,163
Milwaukee	743,414	Omaha, Nebr., and Council Bluffs, Iowa	273,851
Minneapolis and St. Paul	832,258	Peoria	144,732
Providence, R.I., Fall River, and New Bedford, Mass.	963,686	Portland, Oreg.	378,728
Scranton and Wilkes Barre	652,312	Racine and Kenosha	133,463
Washington	621,059	Reading, Pa.	170,486
		Richmond	220,513
Total	6,950,199	Roanoke	103,120
		Rochester	398,591
Akron	346,681	Rockford	103,204
Albany, Schenectady, and Troy, N.Y.	425,259	Sacramento	126,995
Allentown, Bethlehem, and Easton, Pa.	322,172	Salt Lake City	184,451
Altoona	114,232	San Antonio	279,271
Atlanta	370,920	San Diego	181,020
Atlantic City	102,024	San Jose	103,428
Binghampton	130,005	Savannah	105,431
Birmingham	382,792	Seattle	420,663
Bridgeport	203,969	South Bend	146,569
Canton	191,231	Spokane	128,798
Charleston	108,160	Springfield and Holyoke, Mass.	398,991
Chattanooga	168,589	Syracuse	245,015
Columbus	340,400	Tacoma	146,771
Dallas	309,658	Tampa and St. Petersburg	169,010
Davenport	154,491	Toledo	346,530
Dayton	251,928	Trenton	190,219
Denver	330,761	Tulsa	183,207
Des Moines	160,963	Utica	190,918
Duluth	155,390	Waterbury	140,575
El Paso	118,461	Wheeling	190,623
Erie	129,817	Wichita	119,174
Evansville	123,130	Wilmington	163,592
Flint	179,939	Worcester	305,293
Fort Wayne	126,558	Youngstown	364,560
Fort Worth	174,575		
Grand Rapids	207,154	Total	17,226,665
Harrisburg	161,672		
Hartford	471,185	Grand total	54,753,645

Bureau of the Census.

In the discussion of table 7 it was shown that the percentage of shipments of various crops to specified markets did not vary greatly during 1930 and 1931. The percentage of car-lot shipments of each of 16 commodities unloaded in Boston, Chicago, and Pittsburgh for each of the years 1925 to 1931 is shown in table 12.

The percentage of United States car-lot shipments unloaded in a market varies less from year to year than the actual number of cars unloaded. For example, during the period 1925 to 1931 the percentage of United States lettuce shipments unloaded in Boston ranged from 2.7 percent in 1925 to 3.9 percent in 1931; the number of cars unloaded, however, had increased over 90 percent—from 1,021 in 1925 to 1,942 in 1931.

In Chicago in 1926 the apple car-lot unloads amounted to 7,831 cars, representing 5.9 percent of the Nation's shipments, while in 1929 the unloads were only 5,316 cars, but they represented 5.1 percent of the shipments. In 1925 the unloads of 1,306 cars of oranges in Pittsburgh represented 2.3 percent of the shipments, and in 1929, 2,803 cars unloaded represented 2.9 percent of the shipments.

In most instances the percentages do not indicate any definite trend or change in the importance of these cities as markets for the commodities shown in table 12. On the whole, the table indicates that the car-lot distribution from year to year among the various markets is fairly regular and in proportion to the total volume of shipments.

The average relation of car-lot unloads in three markets to shipments for the 7-year period 1925–31 is also shown in table 12. This affords a means of comparing the variations in the percentages among the commodities. For the 7-year period, Boston received only 1.2 percent of the car-lot apple shipments whereas grape and strawberry unloads amounted each to 6.3 percent of the domestic shipments. In Chicago and Pittsburgh, too, there were wide variations among the commodities in the relation of unloads to shipments.

TABLE 12—*Domestic car-lot unloads and their relation to domestic car-lot shipments, 16 fruits and vegetables, in 3 markets, 1925–31*

BOSTON

Commodity	1925		1926		1927		1928		1929		1930		1931		Average	
	Cars	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*
Apples	1,110	0.9	1,621	1.2	848	0.8	1,854	1.5	1,313	1.3	1,252	1.2	1,769	1.8	1,395	1.2
Cabbage	843	2.1	794	2.0	880	2.3	1,242	3.0	1,391	3.1	1,156	3.0	1,398	3.6	1,101	2.7
Cantaloups [1]	1,694	5.0	1,695	5.1	1,749	4.8	1,927	5.0	1,959	4.9	2,003	5.5	1,967	5.4	1,856	5.1
Celery	586	2.8	487	2.5	734	3.0	876	3.4	916	3.6	945	3.6	819	3.7	766	3.2
Grapefruit	1,197	6.0	848	5.3	1,190	6.2	1,046	6.0	1,212	4.8	1,013	5.1	1,470	5.1	1,139	5.4
Grapes	5,248	6.4	4,779	6.1	5,543	6.7	4,648	5.7	4,378	6.6	4,398	6.2	3,226	6.9	4,603	6.3
Lemons	438	3.8	577	4.0	552	4.2	579	4.2	590	3.6	558	3.9	646	3.5	563	3.9
Lettuce	1,021	2.7	1,293	3.1	1,516	3.2	1,691	3.3	1,853	3.5	2,066	3.7	1,942	3.9	1,626	3.4
Onions	1,042	3.4	1,103	3.3	1,356	4.0	1,985	5.6	1,921	5.2	2,061	5.2	1,847	5.5	1,616	4.6
Oranges [2]	3,390	5.9	3,893	5.7	4,603	6.1	4,241	6.6	5,597	5.7	3,952	6.0	5,651	5.9	4,475	6.0
Peaches	925	2.3	1,328	2.3	1,036	2.5	1,316	2.3	1,013	2.9	806	2.1	1,474	3.2	1,128	2.5
Potatoes	7,949	3.3	6,869	3.0	8,145	3.2	10,243	4.0	8,847	3.5	7,760	3.1	7,101	2.9	8,131	3.3
Strawberries	825	6.7	914	6.7	1,233	6.9	1,125	6.0	1,057	5.6	703	6.6	826	6.0	955	6.3
Sweetpotatoes	680	3.7	771	3.4	914	3.6	851	4.0	920	4.2	793	4.2	879	5.4	830	4.0
Tomatoes	1,075	3.8	1,031	4.0	1,399	4.2	1,501	4.9	1,522	4.8	1,656	4.9	1,573	5.7	1,394	4.6
Watermelons	641	1.4	669	1.2	763	1.7	724	1.5	833	1.6	724	1.2	692	1.3	721	1.4

Footnotes at end of table.

TABLE 12.—*Domestic car-lot unloads and their relation to domestic car-lot shipments, 16 fruits and vegetables, in 3 markets, 1925–31*—Continued

CHICAGO

Commodity	1925		1926		1927		1928		1929		1930		1931		Average	
	Cars	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*	*Cars*	*Pct.*
Apples	7,745	6.6	7,831	5.9	6,837	6.7	7,422	6.2	5,316	5.1	5,865	5.5	6,190	6.3	6,744	6.0
Cabbage	1,871	4.7	2,058	5.1	1,877	4.9	2,228	5.4	2,264	5.1	1,849	4.8	1,963	5.1	2,016	5.0
Cantaloups [1]	2,929	8.7	2,925	8.8	3,205	8.7	3,248	8.4	3,553	8.9	3,204	8.9	2,942	8.1	3,144	8.6
Celery	2,376	11.3	2,121	10.9	2,377	9.8	2,302	9.0	2,148	8.4	1,884	7.1	1,560	6.9	2,110	9.0
Grapefruit	1,762	8.8	1,624	10.2	1,726	9.0	1,528	8.7	1,943	7.7	1,821	9.1	2,105	7.2	1,787	8.5
Grapes	6,533	8.0	5,813	7.4	7,018	8.5	5,747	7.0	4,705	7.1	4,827	6.8	3,209	6.8	5,407	7.4
Lemons	897	7.7	862	6.0	898	6.8	978	7.2	1,143	7.1	1,111	7.8	1,241	6.8	1,019	7.0
Lettuce	3,886	10.4	4,287	10.2	4,547	9.7	4,491	8.7	4,857	9.1	4,852	8.7	4,341	8.7	4,466	9.3
Onions	1,801	5.8	2,155	6.4	2,077	6.1	2,235	6.3	2,411	6.5	2,241	5.7	1,885	5.6	2,115	6.1
Oranges [2]	4,026	7.0	3,686	5.4	4,622	6.1	4,867	7.5	6,428	6.6	4,931	7.5	6,322	6.6	4,975	6.6
Peaches	1,998	4.9	2,689	4.6	2,158	5.2	2,374	4.2	1,974	5.6	1,593	4.1	2,901	6.3	2,241	4.9
Potatoes	14,754	6.1	14,777	6.4	15,630	6.2	16,289	6.3	15,817	6.2	16,295	6.5	16,402	6.8	15,709	6.4
Strawberries	942	7.7	1,526	11.2	1,701	9.5	1,590	8.5	1,862	9.9	1,044	9.9	1,306	9.5	1,424	9.4
Sweetpotatoes	1,383	7.4	1,467	6.6	1,859	7.3	1,711	8.1	1,733	7.9	1,636	8.6	1,639	10.2	1,633	7.9
Tomatoes	1,769	6.3	2,102	8.1	2,754	8.3	2,654	8.7	2,399	7.6	2,299	6.7	2,161	7.8	2,305	7.6
Watermelons	2,325	5.3	2,517	4.6	2,397	5.3	2,371	4.9	2,562	4.9	2,822	4.8	2,804	5.4	2,543	5.0

PITTSBURGH

Apples	2,570	2.2	2,628	2.0	2,127	2.1	1,932	1.6	2,598	2.5	2,796	2.6	2,060	2.1	2,387	2.1
Cabbage	1,101	2.8	1,303	3.2	1,228	3.2	1,158	2.8	1,365	3.1	1,323	3.5	1,217	3.1	1,242	3.1
Cantaloups [1]	1,382	4.1	1,222	3.7	1,302	3.5	1,397	3.6	1,643	4.1	1,411	3.9	1,546	4.2	1,415	3.9
Celery	798	3.8	758	3.9	817	3.4	791	3.1	1,016	4.0	991	3.8	882	3.9	865	3.7
Grapefruit	386	1.9	374	2.3	385	2.0	395	2.2	622	2.5	597	3.0	728	2.5	498	2.4
Grapes	2,978	3.6	3,007	3.8	2,498	3.0	3,016	3.7	2,785	4.2	2,867	4.1	1,713	3.7	2,695	3.7
Lemons	192	1.7	313	2.2	370	2.8	368	2.7	472	2.9	410	2.9	504	2.8	376	2.6
Lettuce	974	2.6	1,007	2.4	1,087	2.3	1,198	2.3	1,409	2.6	1,478	2.7	1,259	2.5	1,202	2.5
Onions	853	2.7	858	2.5	800	2.4	824	2.3	1,165	3.2	1,135	2.9	934	2.8	938	2.7
Oranges [2]	1,306	2.3	1,719	2.5	1,988	2.6	1,601	2.5	2,803	2.9	1,945	3.0	2,335	2.5	1,957	2.6
Peaches	914	2.2	1,095	1.9	769	1.9	1,037	1.8	848	2.4	735	1.9	950	2.1	907	2.0
Potatoes	3,896	1.6	3,542	1.5	3,753	1.5	3,565	1.4	4,344	1.7	4,606	1.8	3,999	1.7	3,958	1.6
Strawberries	285	2.3	360	2.6	484	2.7	520	2.8	472	2.5	303	2.9	389	2.8	402	2.7
Sweetpotatoes	809	4.4	834	3.7	1,014	4.0	973	4.6	1,135	5.2	962	5.1	904	5.6	947	4.6
Tomatoes	1,098	3.9	991	3.8	1,392	4.2	1,247	4.1	1,519	4.8	1,355	4.0	1,165	4.2	1,252	4.1
Watermelons	717	1.6	868	1.6	795	1.7	895	1.8	1,014	1.9	1,112	1.9	852	1.6	893	1.8

[1] Includes casaba, Honey Ball, Honey Dew, Persian, and mixed melons.
[2] Includes satsumas and tangerines.

The foregoing discussion indicates that the proportion of United States car-lot shipments of a product, received in a market does not change much from year to year. Whether this is true for specific crops from certain producing districts can be determined by a further examination of shipment and unload data. The percentages of Georgia peach shipments and California cantaloup shipments unloaded in each of 12 leading markets for the years 1924 to 1931 are shown in tables 13 and 14.

TABLE 13.—*Percentage of Georgia peach shipments unloaded in various cities and Georgia shipments by years, 1924–31*

City	1924	1925	1926	1927	1928	1929	1930	1931
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Baltimore	2.0	2.3	2.0	1.5	1.6	1.9	1.0	1.0
Boston	4.8	4.3	4.0	3.6	4.2	4.5	4.4	4.9
Chicago	5.8	6.9	7.4	7.4	6.9	6.9	9.4	8.3
Cincinnati	3.4	2.8	2.7	2.9	3.3	4.8	5.1	3.3
Cleveland	3.8	3.5	3.0	3.2	3.4	4.4	3.5	3.8
Detroit	3.3	4.8	4.5	4.6	4.8	5.3	4.4	6.0
Kansas City	.6	.4	.4	.5	.7	.2	.5	.2
New York	25.1	29.5	22.4	25.9	21.5	39.1	25.2	24.3
Philadelphia	5.8	5.4	4.9	5.3	5.4	8.0	5.4	6.0
Pittsburgh	3.5	3.4	3.7	3.0	3.2	4.0	3.0	3.4
St. Louis	1.9	1.5	2.2	2.0	2.2	1.6	3.1	.8
Washington	.8	.8	1.0	.9	.8	.4	.5	.5
Total	60.8	65.6	58.2	60.8	58.0	81.1	65.5	62.5
Georgia shipments	*Cars* 13,611	*Cars* 13,513	*Cars* 17,963	*Cars* 11,882	*Cars* 15,926	*Cars* 5,298	*Cars* 8,623	*Cars* [1] 13,591

[1] Preliminary.

TABLE 14.—*Percentage of California cantaloup and miscellaneous melon shipments unloaded in various cities and California shipments by years, 1924–31*

City	1924	1925	1926	1927	1928	1929	1930	1931
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Baltimore	1.3	1.3	1.2	1.3	1.3	1.4	1.5	1.7
Boston	4.9	5.2	5.0	4.4	5.0	4.9	5.7	5.2
Chicago	7.5	8.0	8.1	8.7	8.3	8.4	8.5	7.7
Cincinnati	2.0	1.7	1.4	1.5	1.4	1.2	1.4	1.5
Cleveland	2.4	2.5	2.4	2.3	2.1	2.5	2.8	2.5
Detroit	2.1	2.8	2.9	2.8	2.6	4.0	3.2	3.1
Kansas City	1.1	1.0	.9	.9	.9	.8	1.0	1.0
New York	18.2	20.7	23.6	22.0	25.5	29.0	30.3	27.2
Philadelphia	4.4	4.3	4.8	5.8	4.9	6.0	7.1	7.0
Pittsburgh	3.5	3.5	3.0	2.9	3.0	3.4	3.1	3.3
St. Louis	1.9	2.1	1.5	1.5	1.4	1.5	1.7	2.1
Washington	1.1	1.1	1.1	1.0	1.0	1.1	1.2	1.4
Total	50.4	54.2	55.9	55.1	57.4	64.2	67.5	63.7
	Cars	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*	*Cars*
California shipments	19,930	18,707	18,320	22,406	25,307	26,850	23,626	[1] 25,686

[1] Preliminary.

During the period 1924 to 1931 the percentage of Georgia car-lot peach shipments unloaded in 12 leading markets ranged from 58.0 percent in the large crop year of 1928 to 81.1 percent in the small crop year of 1929 (table 13). Exclusive of 1929 the range in the proportion of Georgia shipments marketed in the 12 cities was from 58 to 65.6 percent. The remainder of the shipments, usually about one third, have been marketed in the smaller cities.

The fact that in 1929 when the Georgia crop was short the proportion of the Georgia shipments sent to the 12 cities was high indicates that there is a demand in the large markets that will take a certain quantity of peaches at a higher price than can be obtained in the smaller markets.

In 1929, New York City received 39.1 percent of the Georgia peach shipments, whereas the highest percentage received in New York in any of the other 6 years was 29.5 percent in 1925.

The fact that Chicago received 9.4 percent of the Georgia shipments in 1930 and only 6.9 percent from the short crop of 1929 is explained largely by the size of the peach crop in other States from which Chicago normally draws large shipments. The peach crop in Arkansas, Illinois, and Tennessee was large in 1929 and extremely small in 1930.

In years when production in Georgia and competing States approximates the average, there are not usually wide variations from year to year in the percentage of shipments which go to any market.

In the case of California cantaloups there has been a considerable upward trend in the percentage of shipments taken by a few of the largest markets particularly New York and Philadelphia (table 14). In New York, for example, the proportion of cantaloup unloads increased from 18.2 percent of the California shipments in 1924 to 30.3 percent in 1930, then dropped slightly to 27.2 percent in 1931. Honey Dew, Honey Ball, and miscellaneous melons are included with cantaloups in these computations. These melons have increased in importance during recent years. Some significance may be attached to the fact that in both 1929 and 1930 when the percentages of California cantaloup shipments unloaded in New York were high,

there were short crops of Georgia peaches which compete to a considerable extent with cantaloups.

Although the proportion of California cantaloup shipments marketed in a few large cities has increased over a period of years, the proportion going to any market has not fluctuated sharply from year to year.

The annual car-lot shipments of a product, whether it be on the basis of total United States shipments or shipments from a certain producing district, are for the most part divided among the markets in about the same proportion from year to year.

VARIATIONS IN COMPOSITION OF THE FRUIT AND VEGETABLE SUPPLY IN CERTAIN MARKETS

There is some variation from year to year in the composition of the supply in any market. This is necessarily true because of fluctuations in production. The demand for a commodity in any market may also change somewhat from year to year for various reasons.

In table 15 the car-lot and boat unloads of 16 commodities are considered as 100 percent and the proportion of this supply on a car-lot basis represented by each of the 16 commodities is shown for the years 1925 to 1931 for certain cities. In this table imports as well as domestic car-lot unloads are included. The imports of a few commodities as grapefruit, lemons, onions, and potatoes are of considerable importance in a few cities, particularly New York.

In Boston, grapes have ranged from 17.4 percent of the supply in 1925 to 9.4 percent in 1931 showing a decidedly downward trend. Cantaloups have increased in relative importance in New York and Philadelphia but not in the other markets shown in table 15. Lettuce is a commodity which has increased in relative importance in most of the markets, as for example in Boston, where it comprised 3.4 percent of the supply of 16 commodities in 1925 and 6.2 percent in 1930. In Detroit, however, there was only a slight upward trend in the car-lot lettuce unloads.

In 1926, peaches made up 8.1 percent of the car-lot supply in Detroit and in 1930 only 2.9 percent. Such extreme variations are, of course, caused largely by variations in production from year to year, both of the crop under consideration and of competing crops.

In some instances, at least, there appears to be a correlation between a low percentage of one commodity and a high percentage of a competing commodity in the supplies on the large markets. For example, in such years as 1929 and 1930 when the percentages of peaches in the New York supply were only 2.8 and 3.0, the percentages of cantaloups, a competing commodity, were high, being 7.3 and 7.1 respectively.

The relative importance of the commodities in the car-lot and boat supply in the different markets is generally similar, although there are some pronounced variations. In New York, for example, grapes have averaged 12.5 percent of the car-lot and boat supply of 16 commodities, whereas in Detroit the corresponding figure is 7.0 percent. In Boston, apples made up only 4.1 percent of the supply compared with 10.8 in Pittsburgh. Tomatoes in Pittsburgh have frequently comprised 6 percent or more of the car-lot supply, whereas in other cities where tomatoes are produced locally in larger quantities they

have represented a considerably smaller part of the supply. In Chicago, potatoes have usually amounted to 25 to 27 percent of the supply of 16 commodities, while in New York they have usually amounted to only 16 to 19.

TABLE 15.—*Relation of car-lot unloads of each of 16 fruits and vegetables to total car-lot supply of these commodities in specified markets, 1925–31* [1]

BOSTON

Commodity	1925	1926	1927	1928	1929	1930	1931	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Apples	3.7	5.3	2.4	4.9	3.6	3.8	5.1	4.1
Cabbage	2.8	2.6	2.5	3.3	3.8	3.7	4.1	3.3
Cantaloups [2]	5.6	5.6	5.0	5.1	5.3	6.1	5.7	5.5
Celery	1.9	1.6	2.1	2.3	2.5	2.9	2.4	2.3
Grapefruit	4.0	2.9	3.6	2.9	3.4	3.3	4.5	3.5
Grapes	17.4	15.7	15.9	12.3	11.9	13.2	9.4	13.6
Lemons	1.6	2.0	1.6	1.5	1.6	1.7	1.9	1.7
Lettuce	3.4	4.2	4.4	4.5	5.0	6.2	5.6	4.8
Onions	5.8	4.4	5.3	6.6	5.8	6.5	5.4	5.7
Oranges [3]	11.3	12.8	13.3	11.2	15.2	11.9	16.4	13.2
Peaches	3.1	4.4	3.0	3.5	2.8	2.4	4.3	3.3
Potatoes	28.4	27.0	27.9	30.2	26.8	25.8	22.9	27.0
Strawberries	2.8	3.1	3.6	3.0	2.9	2.1	2.5	2.9
Sweetpotatoes	2.3	2.5	2.6	2.3	2.5	2.4	2.6	2.4
Tomatoes	3.8	3.7	4.6	4.5	4.6	5.8	5.2	4.6
Watermelons	2.1	2.2	2.2	1.9	2.3	2.2	2.0	2.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

CHICAGO

Apples	13.5	13.2	11.0	11.8	8.6	9.9	10.4	11.2
Cabbage	3.2	3.5	3.0	3.6	3.7	3.2	3.3	3.3
Cantaloups [2]	5.1	5.0	5.1	5.2	5.8	5.4	4.9	5.2
Celery	4.1	3.6	3.8	3.7	3.5	3.2	2.6	3.5
Grapefruit	3.2	2.9	2.8	2.6	3.2	3.2	3.6	3.1
Grapes	11.3	9.8	11.2	9.1	7.6	8.2	5.4	9.0
Lemons	1.6	1.5	1.5	1.6	1.8	1.9	2.1	1.7
Lettuce	6.7	7.2	7.3	7.2	7.8	8.2	7.3	7.4
Onions	3.5	4.0	3.7	3.7	4.1	3.9	3.2	3.7
Oranges [3]	7.0	6.2	7.4	7.7	10.4	8.3	10.6	8.2
Peaches	3.5	4.5	3.4	3.8	3.2	2.7	4.9	3.7
Potatoes	25.6	25.0	25.0	26.0	25.6	27.5	27.7	26.1
Strawberries	1.6	2.6	2.7	2.5	3.0	1.8	2.2	2.4
Sweetpotatoes	2.4	2.5	3.0	2.7	2.8	2.8	2.8	2.7
Tomatoes	3.7	4.3	5.3	5.0	4.8	5.0	4.3	4.6
Watermelons	4.0	4.2	3.8	3.8	4.1	4.8	4.7	4.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

DETROIT

Apples	11.8	10.2	8.2	10.4	9.3	8.0	9.0	9.4
Cabbage	3.0	3.7	3.0	3.1	3.2	3.2	3.6	3.3
Cantaloups [2]	5.4	4.3	4.5	4.3	5.4	4.5	4.6	4.7
Celery	4.0	2.8	3.2	3.1	2.9	3.3	3.3	3.2
Grapefruit	3.8	3.0	3.0	2.1	3.2	2.5	4.3	3.1
Grapes	10.3	8.2	7.9	8.8	6.3	5.7	3.6	7.0
Lemons	1.9	2.1	1.6	1.8	1.7	1.8	2.0	1.9
Lettuce	6.0	5.6	6.3	6.1	6.1	6.7	6.2	6.2
Onions	5.4	5.5	5.1	4.7	5.2	5.7	3.4	5.0
Oranges [3]	7.8	9.8	9.5	8.0	11.5	8.0	11.4	9.5
Peaches	7.2	8.1	5.6	6.3	4.9	2.9	6.5	5.8
Potatoes	18.8	21.7	24.8	23.8	24.8	31.6	26.3	24.9
Strawberries	2.3	2.3	3.2	3.8	2.7	2.0	2.7	2.7
Sweetpotatoes	2.6	2.8	3.5	2.7	2.8	2.8	3.1	2.9
Tomatoes	3.7	3.7	5.3	4.9	4.0	5.3	4.6	4.5
Watermelons	6.0	6.2	5.3	6.1	6.0	6.0	5.4	5.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Footnotes at end of table.

TABLE 15.—*Relation of car-lot unloads of each of 16 fruits and vegetables to total car-lot supply of these commodities in specified markets, 1925–31* [1]—Continued

NEW YORK

Commodity	1925	1926	1927	1928	1929	1930	1931	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Apples	11.4	11.7	9.9	9.9	8.6	8.3	9.1	9.8
Cabbage	3.1	3.4	3.3	3.7	4.5	4.6	4.6	3.9
Cantaloups [2]	5.7	5.9	5.7	6.8	7.3	7.1	7.3	6.6
Celery	2.7	2.6	3.4	3.8	3.4	3.6	3.3	3.3
Grapefruit	4.3	3.8	4.1	3.2	3.9	4.8	5.8	4.2
Grapes	14.2	15.0	14.3	11.1	10.7	13.0	9.2	12.5
Lemons	3.5	2.8	2.5	3.0	2.7	3.3	2.4	2.9
Lettuce	6.2	6.6	7.0	7.0	7.3	7.5	6.9	6.9
Onions	6.9	6.4	7.2	9.1	6.3	5.6	5.3	6.7
Oranges [3]	9.1	10.1	9.9	9.2	12.6	10.2	15.1	10.9
Peaches	4.1	4.8	3.7	4.5	2.8	3.0	4.4	3.9
Potatoes	19.0	16.7	17.1	16.9	18.2	17.9	16.2	17.3
Strawberries	1.7	1.3	1.7	1.6	1.4	1.0	1.4	1.4
Sweetpotatoes	1.4	1.7	2.1	1.7	1.4	1.1	.8	1.5
Tomatoes	4.1	4.1	5.5	5.7	5.7	6.2	5.3	5.3
Watermelons	2.6	3.1	2.6	2.8	3.2	2.8	2.9	2.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

PHILADELPHIA

Apples	7.1	7.4	4.6	6.6	5.6	6.1	6.2	6.2
Cabbage	6.4	5.8	5.8	6.6	6.9	6.2	7.7	6.5
Cantaloups [2]	4.1	4.8	5.5	5.8	6.1	6.1	6.1	5.5
Celery	3.8	3.6	4.3	5.1	4.4	4.5	4.3	4.3
Grapefruit	2.9	2.6	3.0	2.7	3.2	3.3	4.3	3.2
Grapes	14.1	13.1	12.5	12.1	8.7	9.4	7.0	10.9
Lemons	1.9	2.1	1.9	2.0	2.1	2.1	2.2	2.1
Lettuce	7.0	7.7	8.4	8.3	8.5	8.5	8.3	8.1
Onions	6.0	5.7	5.8	5.9	5.6	6.1	5.7	5.8
Oranges [3]	8.8	10.2	11.7	10.7	15.5	10.4	14.6	11.7
Peaches	2.8	3.7	2.8	4.4	2.0	2.5	3.2	3.0
Potatoes	24.6	23.0	22.4	19.9	20.4	22.4	19.6	21.8
Strawberries	1.3	1.0	1.3	1.1	1.1	.9	1.1	1.1
Sweetpotatoes	1.2	1.2	1.2	.8	.8	.8	.5	.9
Tomatoes	4.2	3.2	5.0	4.0	4.8	5.6	4.9	4.5
Watermelons	3.8	4.9	3.8	4.0	4.3	5.1	4.3	4.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

PITTSBURGH

Apples	12.6	12.4	10.1	9.2	10.3	11.5	9.5	10.8
Cabbage	5.4	6.2	5.8	5.5	5.4	5.9	5.6	5.7
Cantaloups [2]	6.8	5.8	6.2	6.7	6.5	5.8	7.2	6.4
Celery	3.9	3.6	3.9	3.8	4.0	4.1	4.1	3.9
Grapefruit	2.0	1.8	1.8	1.9	2.4	2.4	3.4	2.3
Grapes	14.6	14.2	11.9	14.3	11.0	11.8	8.0	12.2
Lemons	1.1	1.5	1.8	1.8	1.9	1.7	2.3	1.7
Lettuce	4.8	4.8	5.2	5.7	5.6	6.1	5.8	5.4
Onions	4.5	4.3	4.1	4.0	4.7	4.7	4.3	4.4
Oranges [3]	6.4	8.2	9.5	7.6	11.1	8.0	10.8	8.8
Peaches	4.5	5.2	3.7	4.9	3.3	3.0	4.4	4.1
Potatoes	19.0	17.1	18.0	16.9	17.1	18.9	18.5	18.0
Strawberries	1.4	1.7	2.3	2.5	1.9	1.2	1.8	1.8
Sweetpotatoes	4.0	4.0	4.8	4.6	4.5	3.9	4.2	4.3
Tomatoes	5.5	5.1	7.1	6.4	6.3	6.4	6.2	6.2
Watermelons	3.5	4.1	3.8	4.2	4.0	4.6	3.9	4.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Imports as well as domestic boat receipts are included in this table.
[2] Includes casaba, Honey Ball, Honey Dew, Persian, and mixed melons.
[3] Includes satsumas and tangerines.

These variations in the relative importance of the commodities in the supply received by rail or boat in the different cities may be accounted for partly by variations in local production marketed by truck, and possibly to some extent by differences in food habits of the

populations and differences in trade practices and control of shipments.

On the whole, it appears that the fluctuations in the composition of a market's supply from year to year are not large. In the case of some commodities and some markets, there are pronounced trends in one direction or the other. There are considerable differences in the composition of the supply among different markets in any year.

SUMMARY AND CONCLUSIONS

Competition in marketing is keen and growers and shippers of fruits and vegetables are canvassing all means of increasing market outlets and improving distribution methods. The tables and discussion in this study are intended to supply basic information that will assist growers, cooperative marketing associations, and other shippers in the market distribution of these products.

The distribution among the markets of 800,000 to 1,000,000 cars of fruits and vegetables shipped annually in the United States involves many difficult problems. Speed in handling is necessary because of the perishable nature of most of these commodities. Many of the important producing areas are situated long distances (1,000 miles or more) from the large markets, which are mostly in the northern and eastern part of the United States. Conditions on the markets may change materially during the time a shipment is on the way.

Motor-truck shipments are an important item in the fruit and vegetable supply, but rail and boat shipments still account for a large part of the commercial fruit and vegetable movement. Motor-truck shipments in 1931 probably amounted to roughly 25 percent of the United States shipments moving a distance of 20 miles or more to market, which excludes most of the strictly market-garden supplies. Statistics on motor-truck shipments for most producing areas and data on motor-truck receipts in many markets are not available. Therefore, the analysis in this bulletin is based largely on statistics of car-lot shipments and unloads, and such information as is available on motor-truck movement is used in a supplementary way.

Although market-news reports by public agencies are available on market prices, car-lot shipments, and market receipts, there are practical difficulties in obtaining the most efficient use of this information because the control of shipments of a commodity is usually divided among a number of shippers.

A study of the day-to-day price fluctuations for selected commodities, markets, and periods, indicates some sharp fluctuations in supply which is the chief factor influencing price. On the whole, however, the irregularities in day-to-day distribution are not so great as might be expected. The average wholesale-price change from day to day in 1931 for certain highly perishable commodities, in certain markets, averaged about 8 percent. This does not indicate extremely wide daily fluctuations in supply. When different markets in the same general area are compared, it is usually though not always the case that price changes from day to day are in the same direction, indicating fairly even distribution on the average. The average seasonal wholesale prices on different markets for a certain commodity from a certain producing area usually do not show a wide range. Such variations as occur can frequently be explained by differences in transportation charges.

About two-thirds of the car-lot shipments of 16 fruits and vegetables in both 1930 and 1931 were unloaded in 61 market districts with a total metropolitan population of about 40 percent of the United States population, or 72 percent of the urban population in places of 2,500 or more.

For some commodities the largest cities appear to be better markets than the smaller cities. Some commodities have a wider distribution among the small markets than others. On a basis of car-lot unloads per unit of population there are pronounced differences among markets and groups of markets and among different commodities. These differences can be explained only by a study of each case, taking into consideration local market conditions, motor-truck movement, and other influencing factors. A study of total supplies, including truck receipts for a few cities where records are available, shows relatively small variations from year to year in the total supply of 16 fruits and vegetables per unit of population. For specific commodities, however, the variation from year to year is quite large.

The proportion of total United States car-lot shipments of a commodity unloaded in a market has usually shown only small variations from year to year, although in some instances there were rather wide fluctuations and trends over a period of years. There are wide variations in the percentages of car-lot shipments of different commodities unloaded in any market. Some of these differences can be explained by such factors as distance from producing districts which influences motor-truck receipts, motor-truck distribution from the market, and imports.

On the whole, the distribution of car-lot shipments of fruits and vegetables, either on a basis of shipments for the entire United States or for a specific producing district, is fairly even among the markets from year to year and is proportionate to the volume of shipments.

The composition of the fruit and vegetable supply received by rail and boat differs considerably among the markets, and in any market it varies considerably from year to year, being influenced by the volume and location of production.

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APPLICATION OF STEAM IN THE STERILIZATION OF SOILS

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INTRODUCTION

Soil sterilization [1] as a means of protecting a crop against certain soil-borne diseases is practiced by greenhouse vegetable growers throughout the country. It is also an effective method of combating the nematode, and for the control of certain insects which pass part of their life cycle in the soil. Vegetable growers generally sterilize the soil once a year; it is advantageously done in midsummer between crops. Sterilization of soil by steam is considered the most effective and most economical method.

The earliest use of steam for soil sterilization apparently dates back to 1893. At that time W. N. Rudd, of Greenwood, Ill., effected sterilization by placing soil in a large bin and admitting steam through perforated pipes located at the bottom of the bin. Since that early application of steam sterilization the technic has pro-

[1] The term "sterilization" is not strictly correct since all the micro-organisms are not necessarily killed.

gressed through several stages of development, each apparently showing marked improvement over the preceding one.[2]

COMMON METHODS OF STEAM STERILIZATION

THE STEAM RAKE OR HARROW

The steam rake or harrow is one of the earliest devices utilized for soil sterilization. A framework of pipe is made of a size and shape to fit the beds, and into these pipes are screwed teeth, made of small-size pipe, similar to the teeth of a coarse rake. These pipes which form the so-called "teeth" are closed at the ends by flattening. The steam is emitted through small holes drilled through the pipe teeth near the lower end. The small pipes are about 6 inches long and placed about 6 inches apart in each direction; they are forced into the soil to the desired depth of sterilization. The apparatus is supplied with steam by means of a hose, and the steam finds its way into the soil through the small holes referred to above. Generally there are either two rakes used in a single house or four rakes operated in pairs, end to end, in adjoining houses. The rake ordinarily consists of three main pipes which run crosswise of the house. During the operation, a heavy canvas cover is laid on the beds to prevent the rapid escape of steam.

THE BURIED-PIPE SYSTEM

In the buried-pipe method several perforated pipes of about 1½-inch size are connected to a common header and buried to a depth of about 6 inches. After the bed has been sterilized the pipes are taken up and used in another bed. The perforations are one-eighth or three-sixteenths of an inch in diameter, spaced 12 to 15 inches apart along the bottom of the pipe. When steam is turned on the beds are covered with a heavy canvass to retain the heat and steam. The number and length of the pipes are determined by the size and shape of the beds but, of course, are limited by the available boiler capacity. This method of sterilization is effective but the labor required to bury and change the pipes is large. Time can be saved by utilizing two sets of pipes, one set being moved to a new location while the steam is turned on in the other.

THE INVERTED-PAN SYSTEM

In the inverted-pan system an inverted pan is placed over the soil to be sterilized and steam is admitted to the pan at a pressure

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[2] For more complete descriptions of the practical details of soil sterilization, see the following publications:

BESSEY, E. A. ROOT-KNOT AND ITS CONTROL. U.S. Dept. Agr., Bur. Plant Indus. Bull. 217, 78 pp., illus. 1911.

——— and BYARS, L. P. THE CONTROL OF ROOT-KNOT. U.S. Dept. Agr. Farmers' Bull. 648, 19 pp., illus. 1915.

BROWN, H. D., BALDWIN, I. L., and CONNER, S. D. GREENHOUSE SOIL STERILIZATION. Ind. Agr. Expt. Sta. Bull. 266, 27 pp., illus. 1922.

GODFREY, G. H. ROOT-KNOT: ITS CAUSE AND CONTROL. U.S. Dept. Agr. Farmers' Bull. 1345, 27 pp., illus. 1923.

JOHNSON, J. STEAM STERILIZATION OF SOIL FOR TOBACCO AND OTHER CROPS. U.S. Dept. Agr. Farmers' Bull. 1629, 14 pp., illus. 1930.

NEWHALL, A. G. CONTROL OF ROOT-KNOT NEMATODE IN GREENHOUSES. Ohio Agr. Expt. Sta. Bull. 451, 60 pp., illus. 1930.

——— and CHUPP, C. SOIL TREATMENTS FOR CONTROL OF DISEASES IN THE GREENHOUSE AND THE SEEDBED. N.Y. Cornell Agr. Coll. Ext. Bul. 217, 59 pp., illus. 1931.

only slightly above atmospheric. The pan is generally made from 6 to 9 inches deep. The size and shape of the pans vary according to the size and arrangement of the beds in the greenhouse. The pans used in practice today vary in area from approximately 30 square feet to about 110 square feet. Some of the larger and heavier pans are raised by a mechanical hoisting device and transferred from one position to another by some form of conveyor. The pans are usually made of metal varying from 20-gage to 14-gage material. The type which is transported manually is of course provided with lifting handles.

THE BURIED-TILE SYSTEM

There is apparently a definite trend toward the use of buried drain-tile laid with open joints. Steam is admitted to the tile by means of a pipe header which is in turn fed by the steam-distribution system. There are two general tile methods, the temporary system and the permanent system. In the temporary system several lines of tile are buried at a time. After sterilization of a plot is completed and the tile are cool enough to be handled, they are dug up and used over and over in similar fashion until the entire area to be sterilized has been covered. The tile ordinarily used is common 3- or 4-inch drain-tile and is laid to a depth of approximately 14 inches and spaced approximately 18 inches on centers.

In the permanent system, the tiles are buried and permitted to remain in the soil indefinitely. After years of service it may become necessary to reset some of the tile or to replace some which have become broken due to the effect of excess steam pressure or other cause. Both 3- and 4-inch tile have been used with apparently equal success. The buried-tile system entails the highest initial outlay but the labor required for the process is the least of the several systems.

PHYSICAL PRINCIPLES INVOLVED IN STEAM STERILIZATION

The factors of steam pressure and moisture content of the steam are introduced into almost every discussion of soil sterilization. While some investigators and greenhouse operators have regarded high-pressure steam [3] as essential for satisfactory soil sterilization, this view is not borne out by the known physical properties of steam. Regardless of the initial pressure of the steam, its final pressure when it comes in contact with the soil is always approximately atmospheric. That is, whether the harrow, buried-pipe, inverted-pan or buried-tile plan be used, the pressure of the steam at the point where it is applied for sterilization is only slightly above atmospheric, and for all practical purposes the final pressure may be regarded as atmospheric and its temperature as 212° F., also there is comparatively little moisture in the steam after it expands to the lower pressure. While steam at 150 pounds gage pressure, for instance, is hotter than steam at 10 pounds gage, the steam in either case returns to approximately 212° F. when the pressure is released. In addition, the heat contained in a pound of water in the form of steam is changed very little by raising the pressure.

[3] By high-pressure steam in this connection is meant a boiler steam pressure of 100 to 150 pounds per square inch. Such pressures when judged by the standards of modern power-plant practice are of course decidedly low.

OBJECTS OF INVESTIGATION

The principal objects of this investigation were to find the effect of initial steam pressure on the final moisture content of the soil, the final temperature of the soil, and the quantity of steam needed.

Another point of interest is the effect of the available horsepower on the task of sterilization. For example, the Bureau of Agricultural Engineering has frequently been asked whether there is any appreciable difference in the total amount of steam required to sterilize when a comparatively large boiler horsepower is utilized for a relatively short period as compared with a lesser boiler horsepower when applied for a longer period. Also it is important to know the effect of the rate of steam flow on the resulting pressure of the steam in the tile or under the pan. With a given size and weight of pan and with a given set of soil conditions, the quantity of steam which may be passed under the pan in a unit of time, without heaving the pan, has a definite limit. This limit is reached when the upward force of the steam equals the weight of the pan plus the force of friction of the earth in contact with the pan. In practice, additional weights are generally placed on the corners of the pan.

The pressure developed in the tile is of importance because, as will be demonstrated subsequently, the steam piping system feeding the tile beds can be designed more intelligently when the terminal pressure of the steam is known.

In dealing with saturated steam the maximum attainable soil temperature is definitely limited by the pressure in the tile or under the pan. Some operators have attempted in vain to attain relatively high soil temperatures. From the properties of steam, however, it can readily be seen that in order to attain higher soil temperatures the steam must be superheated [4] to a temperature which is higher than that which corresponds to the pressure in the tile under the pan. The effects of superheated steam on the final moisture content of the soil, the time required, and quantity of steam necessary were studied to a limited degree.

The sizing of distribution mains is evidently important to the man confronted with the design and installation of a steam soil-sterilization system. The test layout described later was therefore designed to yield certain data which would prove of value in a rational design of the piping system.

TEST LAYOUT [5]

The tests were conducted out of doors on a plot of selected soil consisting of a brown fine sandy loam mixed with well-rotted horse manure, so as to approximate a soil frequently found in greenhouses. The mixing was done thoroughly and uniformly with a revolving

[4] Superheated steam is steam, the temperature of which has been raised to a higher degree than that of saturated steam corresponding to its pressure. Steam is superheated by the addition of heat to the steam when it is not in the presence of water in the liquid form. For example in the separately fired superheater used in these tests, the steam after leaving the boiler was passed through an additional set of coils which was heated by an oil burner. Thus the temperature was raised as high as 535° F., which is considerably higher than the temperature corresponding to the pressure at which the steam was generated.

[5] The work was done at the U.S. Naval Engineering Experiment Station, Annapolis, Md., Capt. H. R. Greenlee, officer in charge. The excellent cooperation received from Captain Greenlee and his staff contributed largely to the satisfactory conduct of the work.

bucket-type concrete mixer. Between tests the soil was conditioned by spading and by breaking up the lumps.

The testing bed (fig. 1) was divided into two major sections. Plots 1 to 3, inclusive, were utilized for the tile studies and plots 4 to 12 for studies with the inverted pan. The steam was generated by an oil-fired boiler and maintained constant at the various pressures as required by the conditions of test. The superheater was piped in such

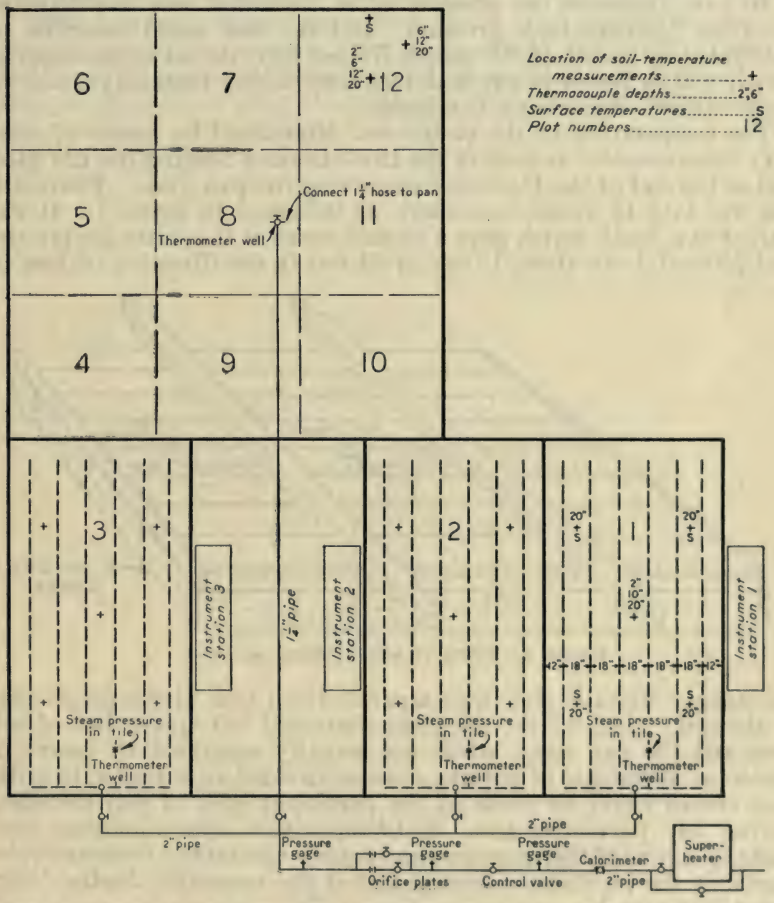

FIGURE 1.—Layout of test plots. Soil temperatures were taken alike in plots 1, 2, and 3, and alike in plots 4, 6, and 12.

a manner that the steam could be passed through it or by-passed around it. The superheater had ample capacity to raise 1,200 pounds of steam per hour to a temperature of 700° F. As may be seen in figure 1, the steam was supplied by a 2-inch pipe and delivered to each of the sterilizing beds by the same size line. Adequate provision was made for valving off any of the individual sterilizing beds. A separate 1¼ inch line, also valved, was provided to deliver the steam to the pan plots. The moisture content of the steam delivered

during the test was determined by means of a standard throttling calorimeter located as shown. The line pressure was determined at the point between the calorimeter and the control valve by means of a calibrated test gage. The quantity of steam supplied was computed from a knowledge of the drop in pressure across calibrated orifices installed as shown. This method of measuring the flow of steam proved simple and accurate.

In most instances the pressure after the orifice was less than the so-called "critical back pressure" and the flow could therefore be calculated by means of the simple Napier formula, an explanation of which will be found in any standard textbook of thermodynamics or a mechanical engineering handbook.

The temperature of the steam was determined by means of mercury thermometers at each of the three headers feeding the tile plots and at the end of the 1¼-inch line serving the pan plots. Four-inch tile was laid 18 inches on centers, as indicated in figure 1. It was buried to a depth which gave a 14-inch cover at the steam-supply end and pitched down about 1 inch in 20 feet in the direction of flow of

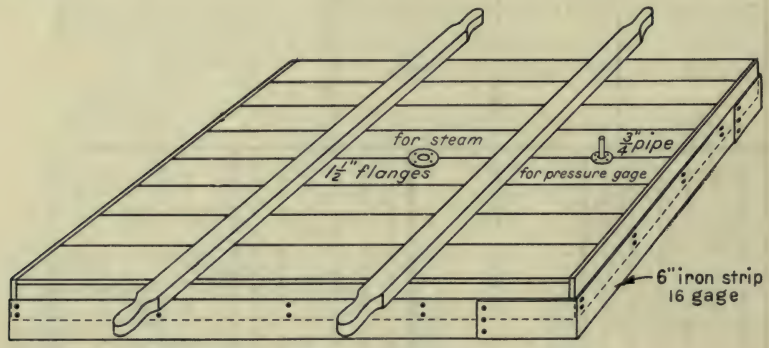

FIGURE 2.—Detail of soil-sterilizing pan used.

the steam. The tile plots were separated by 1-inch planks set on edge in the soil. Each of the tile plots contained 190 square feet of soil area and the pan plots, while not actually separated by means of planks as in the case of the tile, were subdivided as indicated in order that record could be made of the particular plot of soil sterilized during any particular test. Soil-temperature determinations were made by means of thermometers and copper-constantan thermocouples placed in the positions indicated and at the respective depths designated in figure 1.

In addition to the several pressure readings taken on the steam line, the pressures in the tile headers were also determined by means of mercury manometers. In addition to the thermocouples which were placed in the soil at the points indicated above, one couple was used to determine the temperature of the steam under the pan.

Details of the pan used for this investigation are shown in figure 2. The frame of the pan was made of 1-inch boards, was 7 feet square and 6 inches deep, lined on the inside with 24-gage galvanized iron, and had a flange on the outside of 16-gage iron extending 3 inches below the wooden sides.

METHOD OF TEST

It is obvious that a limited experiment like this one, consisting of only 22 separate tests, could not cover all the possible practical conditions involved. However, effort was made to duplicate most of the experiments on at least two different soil plots in order to obtain check data. For example, tests 1 and 2 (table 1) were both made at 20 boiler horsepower with steam supplied at a pressure approximately 8 pounds per square inch gage, but test no. 1 was conducted on plot no. 1 while test no 2 was conducted on plot no. 2. Similarly, when experimenting with the inverted pan, tests nos. 14 and 15 were both made at approximately 10 horsepower with steam at a pressure of 8 pounds per square inch gage, but test no. 14 was conducted on plot no. 12 while test no. 15 was conducted on plot no. 6.

TABLE 1.—*Results of tests of sterilization of soil*

Test no.	Date of test	Plot no.	Boiler power utilized (approximate)	Ratio of square feet of sterilized plot area to boiler horsepower	Pressure of steam in supply main	Temperature of steam entering tile or pan	Time required to attain desired soil temperatures [1]	Steam flow per hour	Steam utilized to attain desired soil temperatures [2]	Steam required per square foot of sterilized plot	Coal required per square foot of sterilized plot	Steam pressure in tile or under pan	Temperature of saturated steam corresponding to tile or pan pressure	Maximum soil temperature attained during sterilization	Quality of steam supplied, in percentage of dryness	Air temperature	Soil moisture		
																	Initial	Final	Increase
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
			Horsepower		*Pounds*	° *F.*	*Hours*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	° *F.*	° *F.*	*Pct.*	° *F.*	*Pct.*	*Pct.*	*Pct.*
TILE																			
1	Aug. 16	1	20	9.5	8	213	4.97	626	3,210	16.9	2.1	0.20	213	212	99	85	13.7	18.0	4.3
2	Aug. 19	2	20	9.5	9	213	3.93	618	2,460	12.9	1.6	.20	213	213	99	81	13.7	17.6	3.9
3	July 18	3	20	9.5	138	212	4.50	607	2,710	14.2	1.8	.23	213	212	95	88	------	------	------
4	July 25	1	20	9.5	140	212	4.75	578	2,860	15.1	1.9	.13	212	212	96	85	------	------	------
5	Aug. 5	2	40	4.8	20	217	1.50	1,186	2,280	12.0	1.5	.43	213	212	99	90	14.4	16.7	2.3
6	Aug. 10	3	40	4.8	26	222	3.47	1,309	4,750	25.1	3.2	.94	215	214	98	85	17.4	22.0	4.6
7	Aug. 25	1	40	4.8	28	[3] 428	2.42	1,301	3,370	17.7	2.4	.24	[3]	321	------	87	15.5	18.1	2.6
8	July 29	2	40	4.8	80	217	1.84	1,249	2,360	12.4	1.6	.46	214	212	96	88	13.1	17.5	4.4
9	Aug. 1	3	40	4.8	84	219	2.62	1,249	4,060	21.3	2.7	.65	214	214	96	86	14.8	18.8	4.0
10	July 26	3	40	4.8	138	218	2.50	1,210	3,325	17.5	2.2	.62	214	212	95	83	10.5	18.5	8.0
11	Sept. 12	2	40	4.8	140	220	2.06	1,235	2,670	14.0	1.8	.81	215	214	95	79	16.2	21.3	5.1
12	Sept. 16	3	40	4.8	144	220	3.68	1,268	4,530	23.8	3.0	.93	215	213	95	76	14.2	17.7	3.5
13	Sept. 20	1	60	3.2	135	227	1.31	1,760	3,090	16.3	2.1	.36	213	212	97	80	13.0	16.8	3.8
PAN																			
14	Aug. 22	12	10	4.9	8	222	------	312	------	------	------	0.10	212	213	99	87	14.9	20.0	5.1
15	Aug. 24	6	10	4.9	8	221	1.65	329	488	10.0	1.3	.04	212	213	99	84	12.3	18.9	6.6
16	Sept. 23	12	10	4.9	75	225	------	309	------	------	------	.13	212	197	96	79	------	------	------
17	Sept. 21	6	10	4.9	155	227	4.40	338	1,340	27.3	3.5	.08	212	214	97	81	17.7	24.2	6.5
18	Aug. 12	12	20	2.5	22	239	.75	609	617	12.6	1.6	.12	212	212	99	80	14.5	19.5	5.0
19	Sept. 6	6	20	2.5	27	[3] 421	.79	626	470	9.6	1.3	.13	[3]	212	------	78	13.4	14.5	1.1
20	Aug. 9	12	20	2.5	83	[3] 535	.50	611	297	6.0	.9	.14	[3]	214	------	87	7.7	10.0	2.3
21	July 20	4	20	2.5	140	239	------	619	------	------	------	.05	212	210	95	87	------	------	------
22	July 28	6	20	2.5	143	239	1.84	618	1,030	21.0	2.7	.08	212	212	97	91	------	16.2	------

[1] Desired temperature for tile method 212° F. at all points and for pan method 180° at depth of 12 inches.
[2] Total quantity of steam has been adjusted to 80° F. initial soil temperature.
[3] Superheated steam.

As may be seen in table 1, during the tile tests the boiler output was 20, 40, or 60 horsepower; which is to say that from 3.2 to 9.5 square feet of ground area were sterilized per boiler horsepower. This probably represents a range such as is found in practice. The steam pressure for the several runs varied from as low as 8 pounds to 144 pounds. The area of ground sterilized at one time by means of the buried tile was always 9 feet 6 inches by 20 feet, or 190 square feet.

In all the tests the steam flow was controlled and measured by means of a calibrated orifice placed in the line. This orifice served the same purpose as does the control valve in a practical installation. The size of the orifice was predetermined by calculation based upon a knowledge of the pressures on each side of the orifice. The pressure before the orifice in each instance was, of course, the line or boiler pressure as tabulated in column 6 of table 1.

The general method in the case of the tile tests was as follows: Steam was admitted to the soil after all thermocouples and other instruments were in place and the sterilizing bed had been covered with building paper. Readings of soil temperatures were taken at regular intervals. The duration of the intervals depended principally upon the rate of temperature change taking place in the soil. This rate was, of course, higher when the larger boiler horsepowers were employed. The beds were heated until all the thermocouples and thermometers reached equilibrium or maximum temperature, the length of time depending principally upon the horsepower employed. The steam pressure, temperature, and calorimeter readings were made every half hour since these did not generally vary to any significant extent. There was a special orifice for each set of conditions of steam pressure and rate of steam flow.

When superheated steam was supplied, the steam was passed through the superheater and the temperature of the superheated steam was controlled by regulation of the oil burner. During the superheat test steam temperatures as high as 535° F. were employed. (To attain this temperature without superheat would require a pressure of about 900 pounds.)

The control and measurement of steam flow when using the inverted pan was similar to that described for the tile tests. It was assumed in the case of the pan, however, that practical sterilization had been attained when the soil reached an average temperature of 180° F. at depth of 12 inches. This would probably be necessary for nematode control, but would be excessive for simple weed elimination as practiced by tobacco growers. Readings of steam pressures and temperatures were taken as in the case of the tile tests. Because of the more rapid rise in soil temperatures, particularly near the surface, it was necessary to take readings at closer time intervals when sterilizing with the inverted pan than was required in the case of the buried tile. The manipulation of the superheater was the same as that described for the tile method. The weight of the pan was augmented by 100-pound weights placed on each corner. This served to hold the pan down and minimized the escape of steam.

68896°—34——2

DISCUSSION OF TEST RESULTS

The test results are presented in table 1 and in figures 3 to 5 inclusive. The tests are arranged in table 1 in order of increasing boiler horsepower supplied as well as increasing pressure of steam supplied. For example, tests nos. 1 to 4, inclusive, are tile tests for all of which approximately 20 boiler horsepower was supplied but the steam pressures in the supply line varied thus, 8 pounds for test no. 1, 9 pounds for test no. 2, 138 pounds for test no. 3, and 140 pounds for test no. 4. Then during tests nos. 5 to 12, inclusive, approximately 40 boiler horsepower was supplied with the steam pressure increasing again from 20 pounds for test no. 5 to 144 pounds for test no. 12. It is important to note that during test no. 7 superheated steam at 428° F. temperature was supplied. In test no. 13, 60 horsepower was supplied at a steam pressure of 135 pounds.

Tests nos. 14 to 22 were conducted with the inverted pan. Again the tests are grouped in order of increasing boiler horsepower and increasing steam pressures. In test no. 19 superheated steam at a temperature of 421° F. was supplied and in test no. 20 steam at a temperature of 535° was supplied.

The curves in figure 3 illustrate the rise in temperature of several of the plots when sterilized by means of the tile and inverted pan and when supplied with steam at various pressures and horsepower ratings. The temperatures plotted for the several depths are averages of the readings taken for the respective depths. As stated above, sterilization was considered complete when all the readings reached 212° F.; in the case of the tile method and when an average temperature of 180° had been attained at a depth of 12 inches in the inverted-pan tests. It will be noted that the deeper thermocouples come up to temperature quicker than do the shallower ones when the tile method is employed, whereas the reverse is true when the inverted-pan method is employed. This of course is because the steam first comes into contact with the soil at a depth considerably below the surface in tile sterilization, whereas it is fed down from the surface in pan sterilization. The greater inherent effectiveness of the buried-tile method is obvious from a consideration of the method of introduction of steam to the soil. A measure of the completeness of penetration of the steam through the soil when using the tile method can be gotten by simply measuring the temperature of the soil at the surface by means of an ordinary mercury thermometer having an upper limit above 212°. If the surface temperature is 212° in a number of places well distributed over the plot, it is certain that the soil between the tile and the surface is also 212°. Also, the steam will have penetrated below the tile to a certain depth, depending upon the degree of compactness.

The difference in the effectiveness of the tile and pan methods of sterilization should be kept clearly in mind, especially in considering the relative fuel costs. The former method sterilizes deeper and heats the soil to a higher average temperature, therefore it is only natural that more fuel will be required by the tile method than by the pan method.

EFFECT OF PRESSURE OF STEAM SUPPLIED ON FINAL TEMPERATURE OF STERILIZED SOIL

In the discussion of the physical principles involved in soil sterilization by the methods used in ordinary greenhouse and outdoor bed practice, it was pointed out that theoretically the maximum soil temperature should be approximately 212° F. because the steam always expands to a final pressure of about atmospheric when

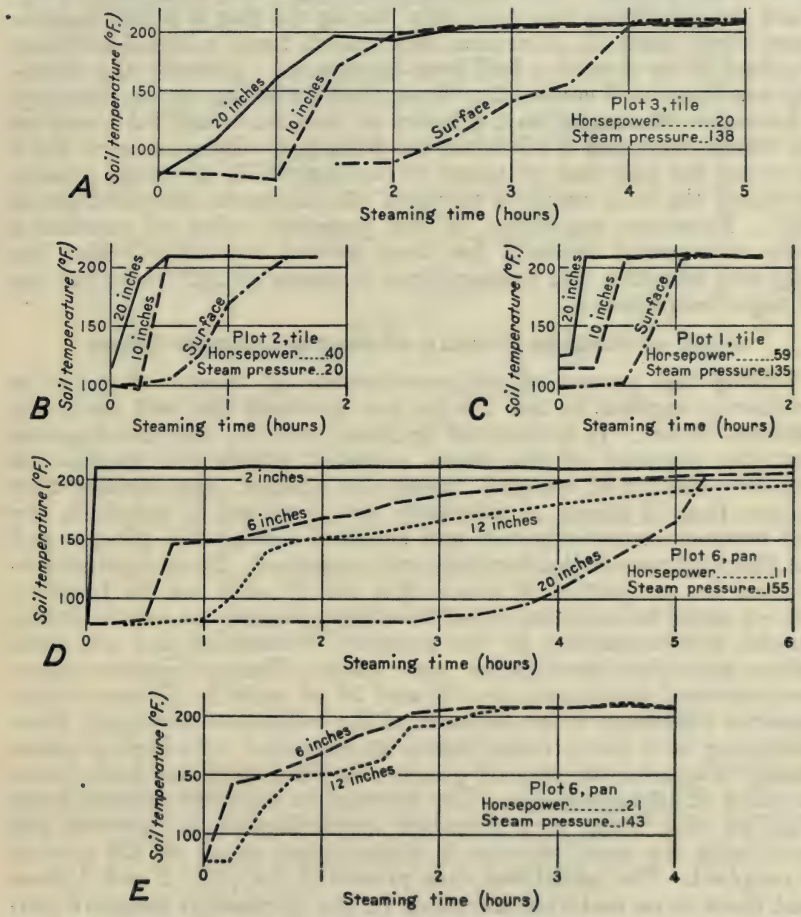

FIGURE 3.—Rise of soil temperature during sterilization: *A*, Tile test, 20 horsepower; *B*, tile test, 40 horsepower; *C*, tile test, 59 horsepower; *D*, pan test, 11 horsepower; *E*, pan test, 21 horsepower.

released in the soil. Also it was shown that even with relatively high initial steam pressures the final temperature would still be approximately 212°.

Column 15 in table 1 and the curves presented in figure 3 show that the test work bears out the theoretical deductions regarding maximum attainable soil temperatures. Except for test no. 7 when superheated steam at a temperature of 428° F. was supplied, the highest

soil temperature reading was 214°, and in about one-half the tests the maximum temperature attained was 212°. Taking into consideration the probable experimental error it can be said that for all practical purposes the maximum soil temperature attainable is 212°.

In the case of superheated steam, the maximum soil temperature attained was 321° F. This temperature was attained, however, only after a comparatively long steaming time, 27 hours actual steaming in a 5-day period. The time to reach 212° was 2.42 hours only. Since the sterilizing was done only during the day it is not possible from these tests to determine how much time would have been required if the steaming had been continuous. Actually the steaming was done on 5 consecutive days, thus 3.5 hours on the first day, 6 hours on the second day, 6 hours on the third day, 5.5 hours on the fourth day, and 6 hours on the fifth day. Between each day's steaming the plot had 18 hours of cooling which no doubt greatly increased the time required to reach the maximum temperature of 321°. However, regardless of the practical value of sterilizing with superheated steam it has been proved conclusively that the only way to attain soil temperatures in excess of 212° is by the use of superheated steam.

EFFECT OF PRESSURE OF STEAM ON MOISTURE CONTENT OF SOIL

During the process of soil sterilization by means of steam as ordinarily applied in the tile or pan methods, the soil obviously becomes wetter. It is believed by some growers and investigators that the pressure of the steam supplied affects the increase in moisture content of the soil during the process. Specifically they believe that if steam at relatively low pressure is supplied, the soil becomes excessively wet and puddled during the process and the thoroughness of the sterilization is impaired. From a consideration of the properties of steam this belief could not be justified, but, in order to learn the effect of steam pressure on soil moisture, careful determinations of the moisture content of the soil both before and after sterilization were made. The soil-moisture data are presented in columns 18, 19, and 20 of table 1. There was no material difference in the increase of the soil-moisture content when sterilizing with low-pressure steam as compared with high-pressure steam. Consider the case of plot no. 6, when sterilized with steam supplied at 10 horsepower. The increase in moisture content when supplied with steam at 8 pounds is approximately 6.5 percent and practically the same increase is shown when steam at 150 pounds is supplied. The additional data presented for plots 2 and 3 show that there is no material difference in the increase in moisture content of the soil regardless of the pressure of the steam supplied. From column 19, table 1 it can also be seen that the final moisture content of the soil was never very high, the maximum for the tile method being 22 percent and for the inverted-pan being about 24 percent. This amount of soil moisture prevailing after sterilization is not objectionable.

EFFECT OF PRESSURE OF STEAM SUPPLIED ON QUANTITY OF STEAM REQUIRED FOR STERILIZATION

Some growers believe that a high initial steam pressure will somehow permit sterilization to be completed in a shorter time and with

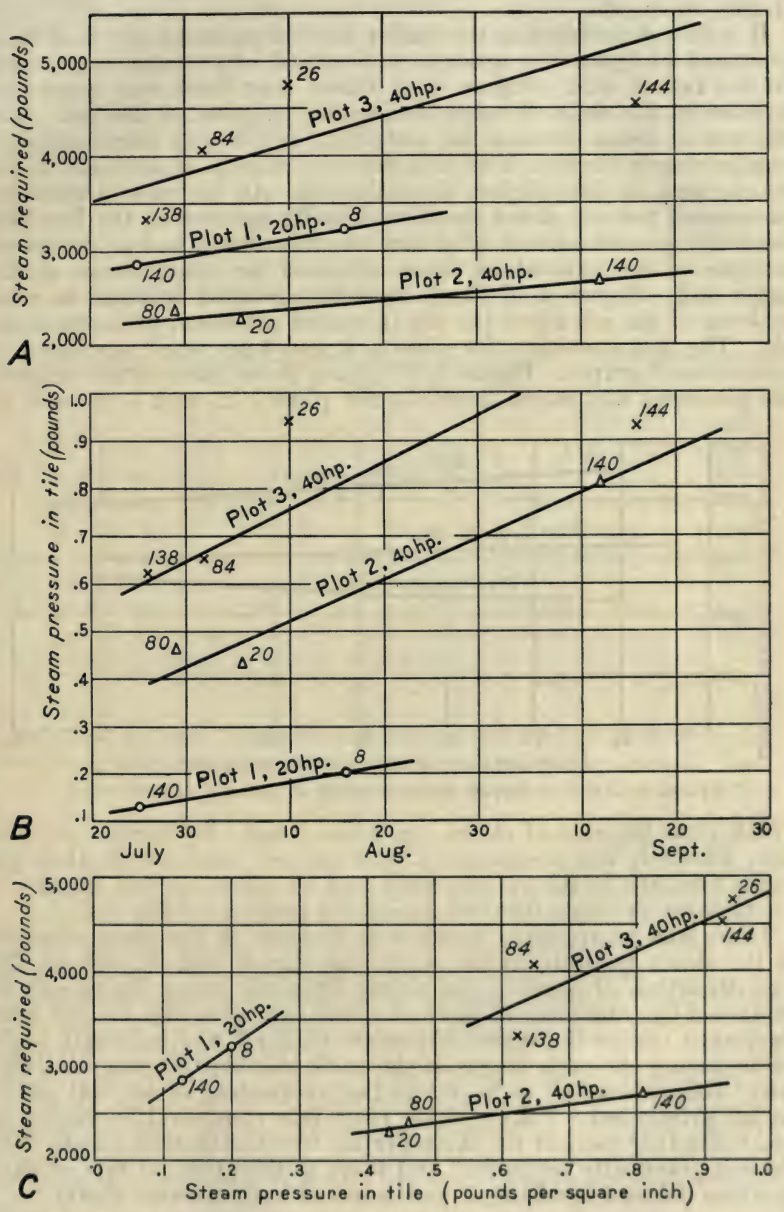

FIGURE 4.—Changes in steam required and in steam pressure in tile during progress of tests, also relation between tile pressure and steam required: *A*, Increase of steam required with time; *B*, increase of pressure in tile with time; *C*, relation between steam required and steam pressure in tile. (Numbers adjacent to plotted points indicate steam pressure in main.)

less total steam demand than would be required if the initial steam pressure were low, even though the steam were supplied to the soil at the same rate.

It is first desirable that the reader have in mind the physical facts presented in figure 4 in order to understand why certain test points do not fall in line. Figure 4, *A* shows that there was a gradual increase in the steam demand during the progress of the test. The increase in steam demand for plots 1, 2, and 3 with the passage of time is clearly shown. This was due no doubt to an increase in the compactness of the soil just above the tile. An increase in the compactness of the soil above the tile naturally resulted in the loss of a relatively greater amount of steam into the subsoil and a consequent increase in the amount of steam required for sterilization of the upper soil. Figure 4, *B* shows how this gradual increase in compactness of the soil above the tile increased the steam pressure in the tile. The characteristics for plots 1, 2, and 3 are again presented in this series of graphs. Figure 4, *C* in turn shows the relation between tile pressures and steam demands for plots 1, 2, and 3, in each of

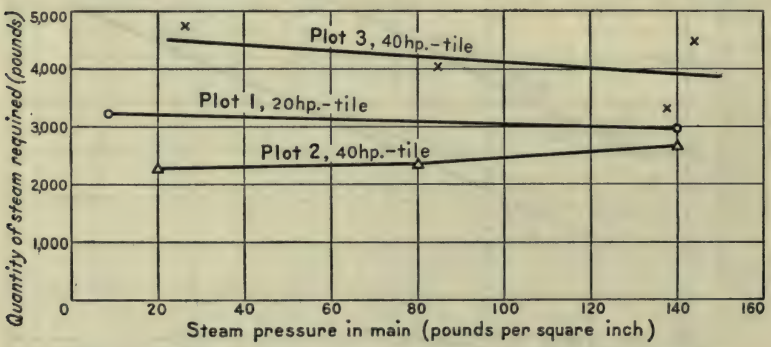

FIGURE 5.—Effect of various steam pressures on quantity of steam used.

which plots the rate of steam input was fixed. By further correlation, which is not presented, it was proved conclusively that the steam pressure in the supply main had no effect on this change in tile pressure or steam demand during the progress of the test.

There was no apparent increase or decrease in the steam demand as the steam pressure in the main was varied (fig. 5, plot no. 3). The departure of some of the points from the curve drawn can be explained by references to figure 4 where it is seen that for the tests conducted late in the season the steam demand was relatively high, while during the early stages of the work the demand was relatively low. This is believed to be due to the compacting of the soil as the season progressed. Taking these facts into consideration it can be concluded that each of the three graphs for the tile tests can be considered practically horizontal and there is therefore no loss or gain in steam demand resulting from the use of high-pressure steam.

EFFECT OF BOILER HORSEPOWER ON QUANTITY OF STEAM REQUIRED

In the cases of both plots nos. 1 and 3 an increase in boiler horsepower shows an increase in the quantity of steam required. In the

case of plot no. 6 when sterilizing by means of the pan an increase in boiler horsepower resulted in a decrease in the quantity of steam required. The increase in the case of the tile may be explained by the fact that as the steam input to the tile is increased, the pressure in the tile is increased and a relatively greater amount of steam is forced down into the deeper soil. There is no apparent reason for decrease in steam demand upon increasing the horsepower in the case of the pan test. It must be clearly understood, however, that even though more steam may be required to utilize the higher boiler horsepower per unit of area in the case of the tile method, there is a time saving which must be taken into consideration when making an estimate of the relative merits of high and low boiler horsepower per unit of soil sterilized. More tests would be required to demonstrate conclusively that the characteristic shown for plot no. 6 holds in general.

EFFECT OF BOILER HORSEPOWER ON STEAM PRESSURE IN TILE AND UNDER PAN

The question of steam pressure in the tile and under the inverted pan is of interest for two principal reasons: (1) Because only a fairly limited pressure can be withstood by either the tile or inverted pan; (2) because some knowledge of the final pressure of the steam must be had for an intelligent design of the piping or steam-distribution system for soil sterilization. The pressure under the pan in the case of plot no. 6 (table 1) remained nearly constant while the boiler horsepower input to the pan was doubled. This probably means that the pan heaved up when 20 horsepower was introduced and a larger quantity of steam was wasted to the atmosphere. On the other hand, the pressure in the tile tests shows the expected increase with an increase in the boiler horsepower input. For example, in plot no. 3, the tile pressure increased from 0.23 pound at 20 boiler horsepower input to 0.62 pound at 40 boiler horsepower input. Correspondingly, in plot no. 1, the tile pressure increased from 0.13 pound at 20 boiler horsepower to 0.36 pound at 60 boiler horsepower input. The tile pressure for plot no. 3 is about twice that for plot no. 1, which explains the higher steam demand for plot no. 3. The higher tile pressure might plausibly be due to a more compact soil above the tile in the case of plot no. 3; this would result in relatively more steam being driven downward with the accompanying increase in time required to attain desired temperatures at the shallower depths. Under all conditions of steam input covered by this investigation, the tile pressure and pan pressure were at all times very low—in fact considerably less than 1 pound.

It is of interest to note that there was a general increase in the steam pressure in the buried tile during the progress of the investigation indicating a steady increase in the compactness of the soil above the tile, probably caused by rains, and by walking on the tile beds. This is shown clearly in figure 4, A and has been discussed in a preceding section.

HORSEPOWER REQUIRED PER UNIT OF SOIL STERILIZED

The grower or greenhouse operator who sterilizes soil by means of steam is sometimes confronted with the problem of determining the relation between boiler horsepower available for soil sterilization and

the size of the plot to be sterilized at one time. In the case of the pan the amount of steam which can be fed into a given pan has a pretty definite limit, depending principally upon its weight. For example with the 7- by 7-foot pan used in these tests, only 20 boiler horsepower could be utilized without heaving even though an additional weight of 400 pounds was placed on the pan. There is no such practical limitation in the case of the tile method.

From the data recorded in table 1 it is obvious that if a relatively small area is sterilized with a given horsepower the time required will be short, whereas if a relatively large area is sterilized the time required will be longer. The largest ratio employed in these tests when utilizing the buried tile was approximately 10 square feet of soil per horsepower. Sterilization at this ratio required from 4 to 5 hours for completion. When the time required for preparing the bed for sterilization is taken into consideration it can be seen that just about one complete working day will be required for a given plot. Roughly 1 square yard per boiler horsepower can therefore be assumed as a practical maximum ratio of soil area to boiler horsepower for the tile method. The maximum ratio in the case of the inverted pan is limited generally by the total weight of the pan, and any weights which may be added to the pan. The weight of the pan is in turn limited by the ability of an ordinary crew to manipulate it. The greatest horsepower input which was permissible with the pan used in these tests gave a ratio of about 2.5 square feet of soil to 1 boiler horsepower. For the ordinary pan handled by a small crew 3 square feet of soil area per boiler horsepower should prove feasible in most cases.

Since the labor requirements in the pan method are relatively important the object is to sterilize as quickly as possible and therefore to use as low a ratio of soil area to boiler horsepower as feasible. On the other hand the labor requirement with the permanent buried tile is not relatively important and the objective is rather to handle a larger area of soil per boiler horsepower. The boiler horsepower is one of the important limiting factors in the case of tile sterilization.

COAL REQUIRED PER SQUARE FOOT OF STERILIZED PLOT

The coal required per square foot of sterilized plot is given in column 12 of table 1. The average value for the buried-tile method is about 2 pounds of coal per square foot. The average value for the inverted pan (attaining a temperature of 180° F. at a depth of 12 inches) is also about 2 pounds. This value checks very closely with figures obtained from growers who have kept accurate cost records for greenhouse-soil sterilization. However, 2 pounds of coal per square foot is undoubtedly more than ordinarily is used for the partial sterilization employed in connection with tobacco-seed beds.

PIPING

The following discussion, together with table 2, illustrates a method of design of steam supply mains for soil-sterilization purposes. Suppose that it is desired to determine the size of main required to convey the sterilizing steam for a greenhouse range in which the farthest plot is approximately 500 feet from the boiler and in which 250 boiler

horsepower is to be utilized with steam at an initial pressure of 150 pounds. From table 2 it is readily seen that a 3-inch main would be necessary. The distance from the boiler to the farthest plot should of course be measured along the course of the pipe itself rather than in a straight line.

TABLE 2.—*Sizes of steam mains and boiler horsepower for soil sterilization in greenhouses*

Boiler horsepower	Size of pipe required in—							
	Mains 500 feet long where the boiler pressure is—				Mains 1,000 feet long where the boiler pressure is—			
	10 pounds	50 pounds	100 pounds	150 pounds	10 pounds	50 pounds	100 pounds	150 pounds
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
10	2	1¼	1	1	2½	1½	1¼	1¼
15	2½	1½	1¼	1	3	2	1¼	1¼
25	3	2	1¼	1¼	3½	2½	1½	1½
35	3½	2½	1½	1½	3½	2½	2	1½
50	3½	2½	2	1½	4	3	2½	2
75	4	3	2½	2	5	3½	2½	2
100	5	3½	2½	2	5	4	3	2½
150	6	4	3	2½	6	5	3½	3
200	6	5	3½	3	8	5	4	3½
250	8	5	3½	3	8	6	5	3½
300	8	6	4	3½	10	8	5	4
350	8	6	5	3½	12	8	6	5
400	10	6	5	4	12	8	6	5

Since it has been demonstrated that low-pressure steam may be used very effectively for soil sterilization, it is feasible to use the steam-heating mains as distribution pipes for such low-pressure sterilizing steam. In this case it is not a matter of sizing the pipes but rather determining the amount of the available boiler capacity which may be handled by the existing mains. The capacity of a heating main is greatly increased over that required for heating purposes when utilized to convey steam for sterilization because the back pressure ordinarily imposed by the heating system is removed and the steam is allowed to pass freely into the soil. In fact it is safe to assume that the carrying capacity is thus increased approximately four times. To illustrate the method of handling the steam when the heating mains are utilized for distribution, consider the case of a range of eight greenhouses, 35 feet wide and 125 feet long, each requiring approximately 15 boiler horsepower for heating. Let it be assumed also that a 150-horsepower boiler is used to supply the heating steam. Since as stated above the heating-line capacity can safely be increased four times to determine the sterilizing-steam capacity, steam to the extent of approximately 60 boiler horsepower can be conveyed to each of the houses by the existing heating mains for the purpose of soil sterilization. Thus one-half the available boiler capacity can be passed into a given house for the purpose. If it be desired to utilize the entire boiler capacity and sterilize the entire range in a relatively short time the steam could be delivered to two of the houses and sterilization could be done simultaneously in each. If it is assumed that 1 square yard of soil is to be sterilized

per boiler horsepower it can readily be seen that about one-eighth of each of the two houses can be sterilized at a given time if the entire normal boiler capacity is employed. When special lines are used to carry low-pressure steam for soil sterilization they should be sized in accordance with the data given in table 3 in a manner similar to that outlined for the high-pressure steam example given above.

TABLE 3.—*Number of branch lines or headers equivalent to various main and branch sizes*

Size of main (inches)	Number of buried-tile lines that can be used when size of branch pipe or header is—						
	½ inch	¾ inch	1 inch	1¼ inches	1½ inches	2 inches	2½ inches
¾	2	1					
1	4	2	1				
1¼	7	4	2	1			
1½	11	5	3	2	1		
2	20	10	5	3	2	1	
2½	31	15	8	4	3	2	1
3	54	26	15	7	5	3	2
3½	78	38	21	11	7	4	3
4		52	29	15	10	5	3
5			50	25	17	9	6
6				40	27	15	9
8					55	30	19
10						52	33
12							52

It is necessary that a certain amount of care be given to the sizing of the branch lines leading from the main supply line to the buried tile. Referring to table 3 let it be assumed that a 4-inch supply line is being used to carry steam which is to be distributed to 11 buried-tile lines and it is desired to determine the proper size of branch line to each tile line. Entering at 4 in the first column of table 3, and reading across horizontally to 10, which is the closest number to the 11 lines assumed in the example, and then moving up vertically to the top line we find that each branch line should be 1½ inches in size. Similarly if the main is 2 inches in diameter and there are 10 tile lines we find that each branch line should be three-fourths of an inch in diameter.

CONCLUSIONS

In the experiments herein reported the following conclusions seem warranted:

It is not possible to obtain a soil temperature in excess of about 212° F. without the use of superheated steam.

The moisture content of the soil increases during sterilization but the increase is not materially affected by variations in steam pressure.

Increasing the initial steam pressure does not decrease the quantity of steam required to sterilize the soil.

The pressure of the steam under the pans remains constant at the various boiler horsepowers due to heaving of the pan and increased escape of steam into the air as the boiler horsepower is increased. The pressure in the tile increases as the boiler horsepower is increased.

With the tile method roughly 1 square yard of soil may be sterilized per boiler horsepower. With the pan method 3 square feet per boiler horsepower may be sterilized.

About 2 pounds of coal are required per square foot of soil surface with both the tile and pan methods.

The capacity of a steam heating main is greatly increased when used to convey steam for sterilization because of the absence of appreciable back pressure.

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BRIDGE PIERS AS CHANNEL OBSTRUCTIONS

By

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BRIDGE PIERS AS CHANNEL OBSTRUCTIONS

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INTRODUCTION

This bulletin presents the results of about 2,600 experiments on the obstructive effect of bridge piers to flow of water, using larger piers and a more extensive range of conditions than has hitherto been attempted. The tests were conducted by the Bureau of Agricultural Engineering and the University of Iowa during 1927 to 1931, at the hydraulic laboratory of the university at Iowa City, Iowa.

The investigation was undertaken for the purpose of determining (1) the effect of shape of pier upon the height of backwater caused by the pier, (2) the effect of length of pier upon the height of back

[1] The author acknowledges his indebtedness to Sherman M. Woodward and the late Floyd A. Nagler of the University of Iowa for assistance as consulting engineers during the conduct of the experiments and preparation of the report of this investigation. He acknowledges also the assistance and suggestions given by Martin E. Nelson, engineer, of the U.S. Engineer Office, and by Ralph W. Powell of Ohio State University. Paul L. Hopkins, junior civil engineer, of the Bureau of Agricultural Engineering, assisted in running the tests and making the computations, as did also Jesse C. Ducommun, C. L. Barker, Harold E. Cox, J. Stuart Meyers, R. N. Weldy, Nolan Page, L. H. Heskitt, H. E. Howe, Montok Tom, R. N. Brudenell, R. A. Kampmeier, Frank W. Edwards, and C. H. Morris, graduate and senior engineering students in hydraulics at the University of Iowa.

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water, and (3) the effect of magnitude of channel contraction upon the height of backwater.

The problem of the obstruction of bridge piers to the flow of water is becoming more important with the passing of time. Population is increasing. Industrial and manufacturing interests also are increasing. The larger streams are witnessing a great revival of inland-waterway transportation, and the railroads themselves utilize the easy grades of the river bottoms for their roadbeds, while power plants, both steam and hydroelectric, are generally located at the riverside, all resulting in the concentration of industrial development along streams. This in turn means an increasing number of bridges, which results in a larger number of piers. Also, prices of materials for steel and alternate construction types, as well as other considerations, may tend to promote building of short-span bridges with many piers. Hence, it becomes important to determine what forms of piers offer least obstruction to the flow of water, and how much difference there is in the hydraulic efficiency of different shapes.

The amount of obstruction which a bridge pier causes depends upon (1) the shape of the pier nose, (2) the shape of the pier tail, (3) the percentage of channel contraction caused by the pier, (4) the length of the pier, (5) the angle which the pier makes with the thread of the stream, and (6) the quantity of flow.

BACKWATER OCCURRENCE

The erection of one or more bridge piers in a stream forces the river to flow through a reduced cross section and hence in passing through this section, the water must acquire a velocity greater than that existing in the unobstructed channel.[2] The increase in velocity can be produced only by elevating the water surface in the reach upstream from the piers which produce the contraction in area. Thus, as the stream enters the contracted area, a drop in the water surface is noted accompanying the increase in velocity. However, when the stream expands again into the unobstructed channel downstream from the pier, the water surface fails to rise again to the level of the water surface upstream from the pier. This permanent drop in water level is indicative of energy losses which may originate from three sources, (1) friction of the water on the pier walls, (2) contraction of flow caused by the pier nose, and (3) expansion of the stream as it passes out from between the piers.

The changes in cross section and velocity in passing the bridge piers cause much disturbance in the flow, especially when the pier does not conform in shape to the direction of the contracting filaments of water. The curvature of the stream lines around the upstream nose of a pier induces high and erosive velocities at that point. Eddies may be formed along the sides and below the tail of the pier. These high velocities and resultant eddies often scour out the beds of streams next to the piers to such an extent that the foundations may be endangered and even undermined. Like many other hydraulic phenomena, the height of backwater varies with the square of the velocity of the water, and thus with the square of the quantity of flow

[2] It is assumed that the velocity of the water in the unobstructed channel is less than critical. If the velocity of the water in the unobstructed channel is at critical stage or greater, then the water will rise at the point of obstruction. This condition of flow is seldom encountered in actual practice.

if the depth of water remains the same. Thus doubling the discharge would quadruple the amount of backwater caused by the pier. In many formulas the height of backwater also varies inversely with the square of the coefficient of contraction.

Lawsuits sometimes occur because of damages caused by backwater due to bridge piers. If such damages seem probable, the engineer in designing the bridge for a certain location may calculate by means of some formula the height of backwater that may result from construction of the bridge. Every backwater formula contains a coefficient which varies with the shape of the nose and tail of the pier. Thus the accuracy of the calculation depends greatly upon the correctness of this coefficient, which can be determined only by experiment.

PRINCIPAL EARLIER BRIDGE-PIER STUDIES

Probably one of the earliest writers on the obstruction of bridge piers to flow of water was Dubuat (*5*),[3] who in 1786 attempted to show by mathematics that the nose of a pier should have convex curves to cause the minimum obstruction to flow. Dubuat also derived a formula for computing the amount of backwater caused by different velocities, and by various percentages of channel contraction. In addition he conducted some experiments in losses of head caused by bridge piers. About this same time Bossut (*2*), in a mathematical solution, proved to his own satisfaction that the pier nose should be triangular, the tip being a right angle. Eytelwein (*6*) in 1801 presented a bridge-pier formula in his handbook on hydraulics.

These early hydraulicians were followed in turn by Dupuit, Gauthey, D'Aubuisson (*1*), Debauve (*4*), and Weisbach (*16*, *17*). The last about 1862 performed a few experiments on a small round pier, 0.02 meter in diameter in a channel 0.028 meter wide. This was a much greater percentage of channel contraction than is usually found in practice. His channel was so small that the experiments may be of questionable value. Cresy (*3*) in 1865 reported eight experiments he had made on various shapes of piers 15 centimeters in thickness tested in a canal in which the depth of the water was controlled by stop boards.

Investigations were made in 1914 by Nagler (*9*), who conducted 256 tests on 34 model piers of various types at Ann Arbor, Mich. He suggested a new formula for computing backwater caused by bridge piers, and derived coefficients for use in it. His tests were made on single piers 6 inches wide placed in the center of a channel 2.138 feet wide, contracting the channel 23.3 percent. In 1915–16 Lane (*8*) conducted at Dayton, Ohio, a series of experiments on the flow of water through contractions in an open channel 6.8 feet wide. His tests were made with the following contractions: A 1-foot opening with rounded edges; a 1-foot and a 2-foot opening each with sharp edge contractions; short flumes with 1-foot openings and with both sharp and rounded edges; and an expanding or Venturi flume. These conditions caused 70.5 and 85.3 percent contraction. Lane computed coefficients for use in the D'Aubuisson and Weisbach formulas, and pointed out certain conditions that somewhat limit the use of D'Aubuisson's formula.

[3] Italic numbers in parentheses refer to Literature Cited, p. 25.

From 1917 to 1922 Rehbock (*10; 11; 12; 13; 14, pp. 106–115*) carried on at the hydraulic laboratory of the technical Hochschule at Karlsruhe, Germany, an elaborate series of tests on bridge piers of various sizes and shapes and developed formulas for computing the amount of backwater. As a result of more than 2,000 experiments, the effort to develop a backwater formula suitable for all possible flow conditions was abandoned, and flow past piers was divided into three classes.

While considerable experimental work has been done on piers of solid construction, no tests prior to those reported herein for the first time have ever been made, so far as the writer knows, on piers consisting of two circular pillars connected either by a web of structural braces or by a solid diaphragm. Fowler states, in his discussion of Nagler's paper on bridge-pier tests (*9*), that this type of pier which is now used widely offers much greater resistance to flow of water than the ordinary forms of solid masonry.

The amount of obstruction to flow is increased when the piers are set at an angle with the thread of the stream, but apparently this is another problem of installation that never has been investigated before.

SCOPE OF THE INVESTIGATIONS

In this investigation, tests were run on piers giving four percentages of channel contraction, namely, 11.7, 23.3, 35, and 50 percent. Each pier model was built up of a rectangular barrel 3 feet 6 inches long, and a nose and a tail of lengths depending upon their shapes and upon the width of the pier.

The first series of tests was run on a single pier 14 inches wide placed in the center of the testing canal 10 feet wide. Each "square" or semicircular or 90° triangular end added 7 inches to the barrel length, and other shapes added somewhat more. The twin cylinders were 3 feet 6 inches apart on centers. The over-all lengths of the piers thus ranged from 4 feet 8 inches to 6 feet 7 inches. Eleven combinations of end shapes were tested, as follows:

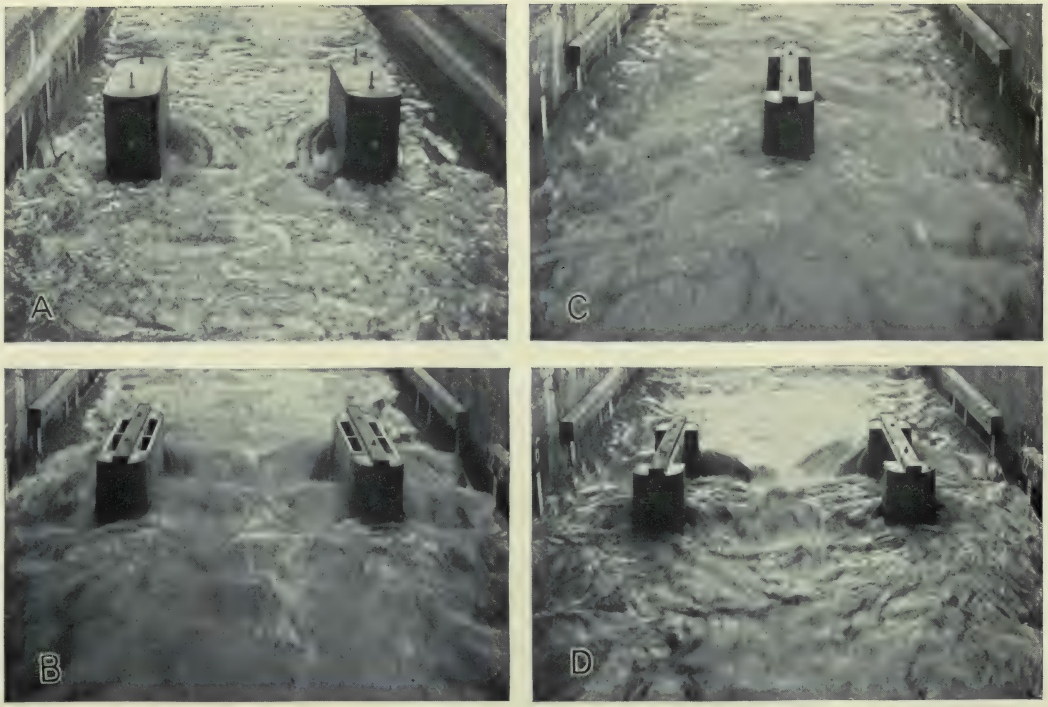
1. Square nose and square tail.
2. Square nose and semicircular tail.
3. Semicircular nose and semicircular tail.
4. Semicircular nose and square tail.
5. Triangular nose of 53° angle and semicircular tail.
6. Triangular nose of 60° angle and semicircular tail.
7. Triangular nose of 90° angle and semicircular tail.
8. Convex nose and tail each formed by two curves tangent to sides of pier and described on an equilateral triangle.
9. Lens-shaped nose and tail each formed by two convex curves tangent to sides of pier and of radius twice the pier width.
10. Twin-cylinder pier without diaphragm.
11. Twin-cylinder pier with diaphragm.

The second series of tests was run on two piers each 14 inches wide placed in the 10-foot canal, doubling the percentage of channel contraction used in the first series. These tests covered the following 14 combinations of end shapes:

1. Square nose and square tail.
2. Semicircular nose and semicircular tail.
3. Convex nose and tail.
4. Lens-shaped nose and tail.

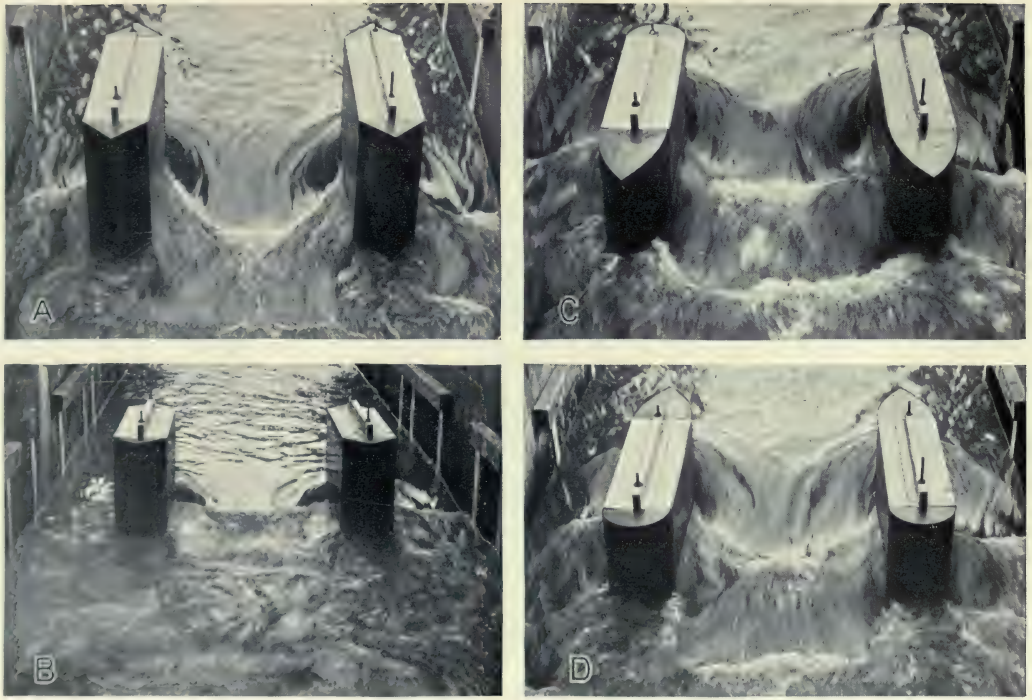
FLOW PAST PIERS OF DIFFERENT SHAPES.

Piers of standard length, four times width. *A*, Twin-cylinder pier without diaphragm; channel contraction 11.7 percent. *B*, Twin-cylinder piers with diaphragm; channel contraction 23.3 percent. *C*, Piers with convex noses and convex tails; channel contraction 23.3 percent.



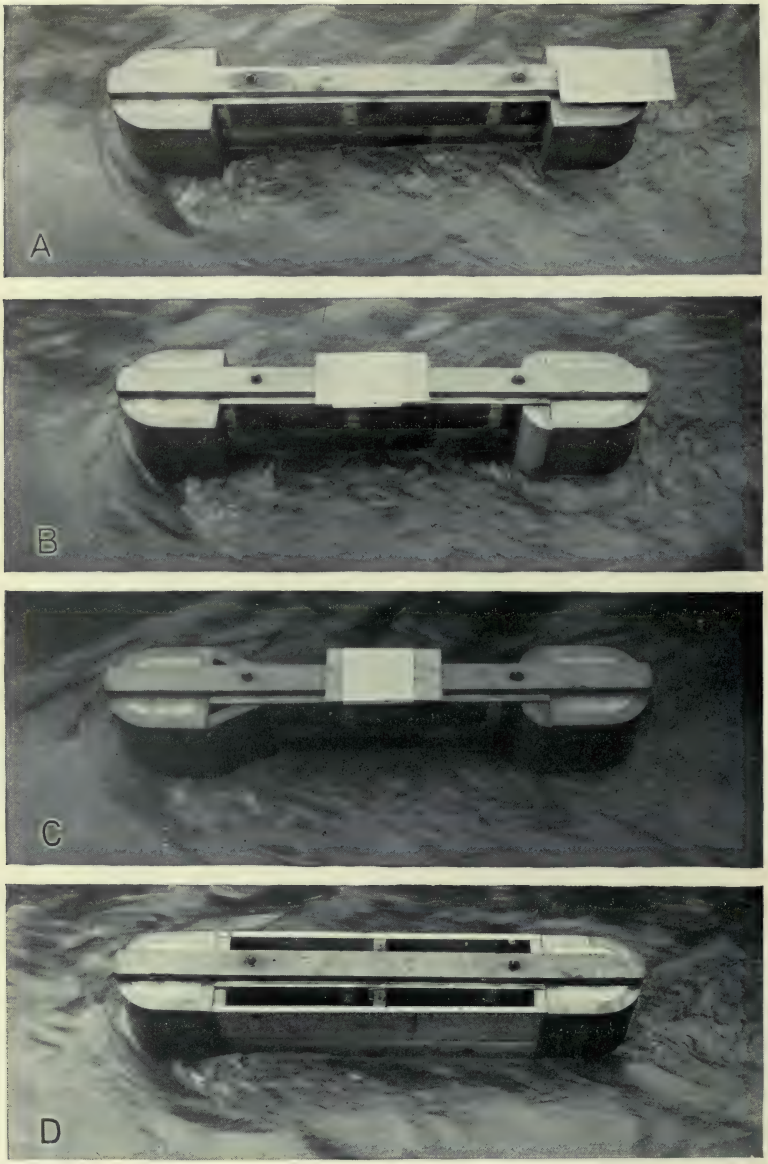
FLOW PAST PIERS OF DIFFERENT SHAPES.

Piers of standard length, four times width. *A*, Piers with semicircular noses and tails; channel contraction 23.3 percent. *B*, Piers with semicircular noses and tails, and batter 1:24 all around; channel contraction 23.3 percent, $Q=82.23$ cubic feet per second, $D_1=2.60$ feet. *C*, Pier with semicircular nose and tail having 1:24 batter, web recessed; channel contraction 11.7 percent, $Q=82.56$ cubic feet per second, $D_1=2.64$ feet, $D_3=2.60$ feet. *D*, Piers with semicircular noses and tails having 1:24 batter, web recessed; channel contraction, 23.3 percent, $Q=82.5$ cubic feet per second, $D_1=2.71$ feet, $D_3=2.61$ feet.



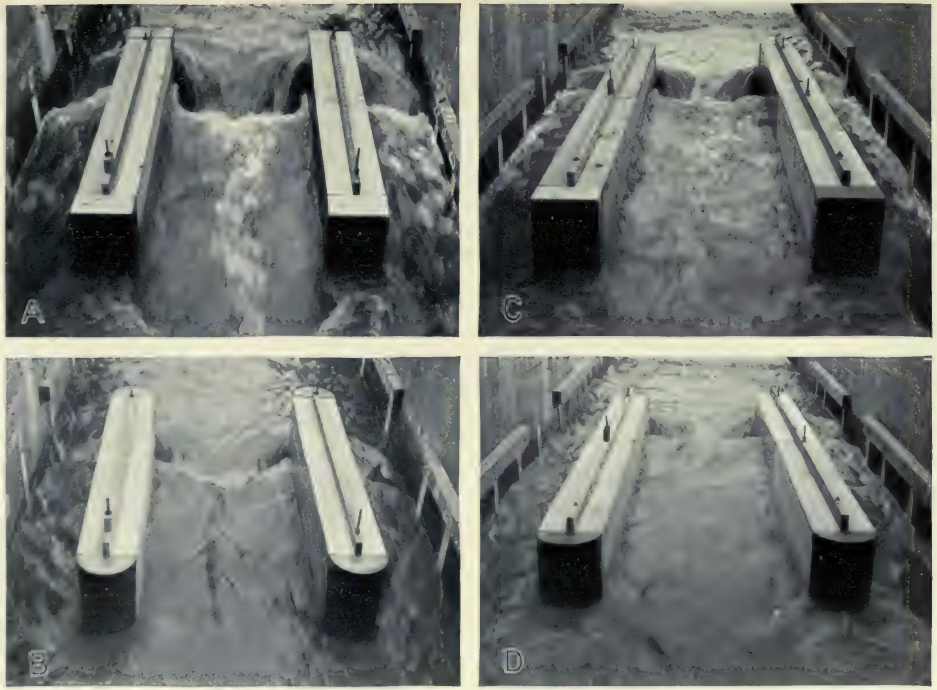
FLOW PAST PIERS OF DIFFERENT SHAPES.

Piers of standard length, four times width. *A*, Piers with 90-degree triangular noses and tails; channel contraction 23.3 percent, Q=30.9 cubic feet per second, D_1=1.18 feet, D_3=1.08 feet. *B*, Piers with 90-degree triangular noses and tails and 1:12 batter; channel contraction 23.3 percent, Q=42.5 cubic feet per second, D_1=1.62 feet, D_3=1.56 feet. *C*, Piers with semicircular noses and lens-shaped tails; channel contraction 23.3 percent, Q=67.7 cubic feet per second, D_1=2.17 feet, D_3=2.11 feet. *D*, Piers with lens-shaped noses and semicircular tails; channel contraction 23.3 percent, Q=67.7 cubic feet per second, D_1=2.15 feet, D_3=2.11 feet.



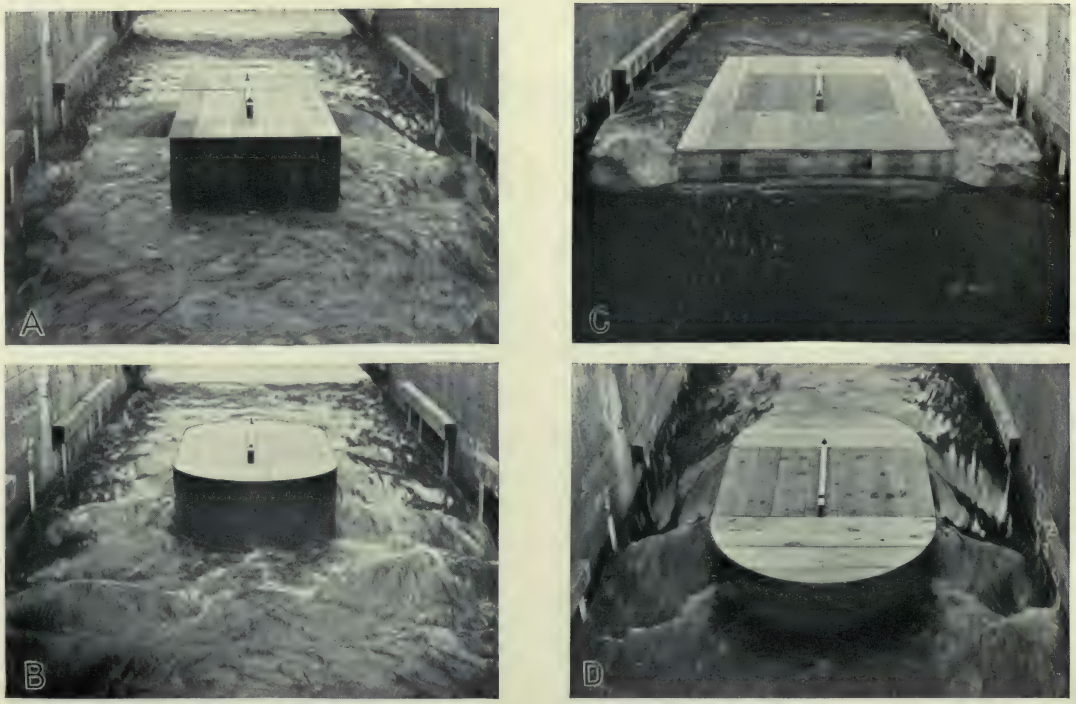
FLOW PAST PIERS WITH SEMICIRCULAR NOSE AND TAIL HAVING 1:24 BATTER, AND WITH DIFFERENT WEB CONSTRUCTION.

Piers of standard length, four times width. Channel contraction 11.7 percent. *A*, No fillets at ends of recessed web. *B*, Quarter-round fillets in web recesses at tail. *C*, Quarter-round fillets at tail and triangular fillets at nose in web recesses. *D*, Web same thickness as nose and tail.



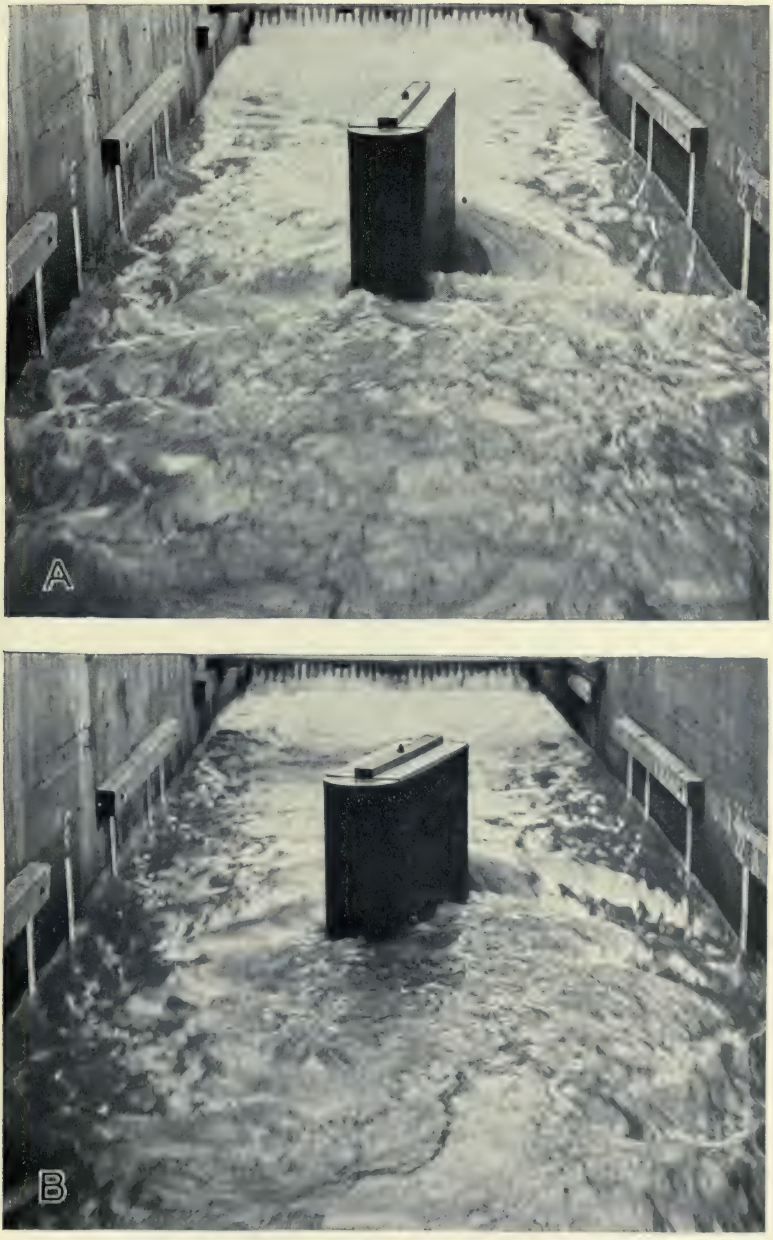
FLOW PAST LONG PIERS.

Channel contraction 23.3 percent. *A*, Piers with length seven times width, and square noses and tails; $Q=78.0$ cubic feet per second, $D_1=2.53$ feet, $D_3=2.44$ feet. *B*, Piers with length seven times width, and semicircular noses and tails; $Q=50.0$ cubic feet per second, $D_1=2.03$ feet, $D_3=2.00$ feet. *C*, Piers with length thirteen times width, and square noses and tails; $Q=75.0$ cubic feet per second, $D_1=2.36$ feet, $D_3=2.28$ feet. *D*, Piers with length thirteen times width, and semicircular noses and tails; $Q=77.0$ cubic feet per second, $D_1=2.53$ feet, $D_3=2.46$ feet.



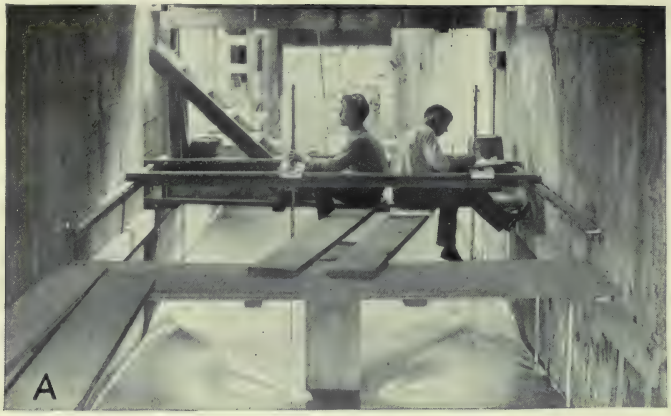
FLOW PAST WIDE PIERS.

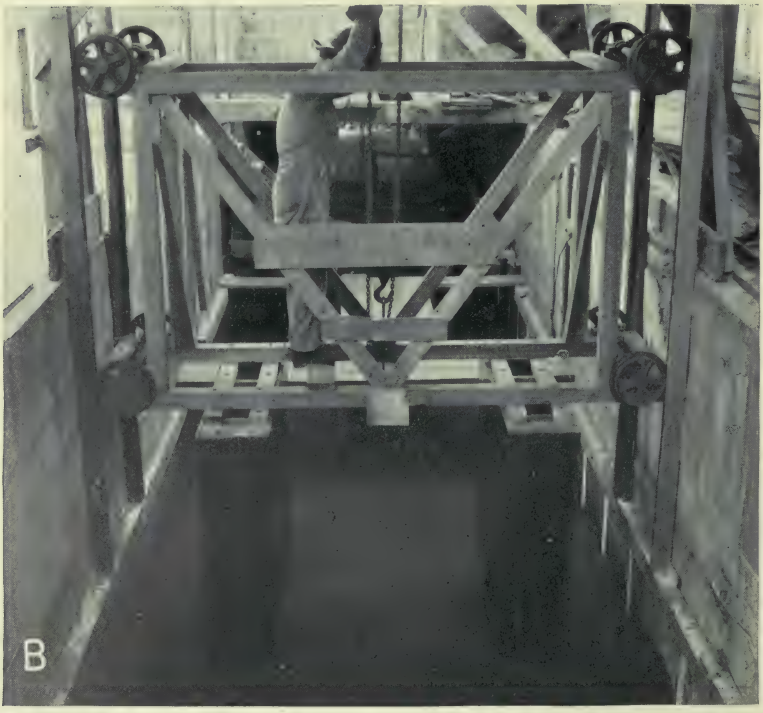
A, Pier with square nose and tail; channel contraction 35 percent; Q=64.3 cubic feet per second, D_1=2.66 feet, D_3=2.55 feet. *B*, Pier with semicircular nose and tail; channel contraction 35 percent; Q=62.3 cubic feet per second, D_1=2.48 feet, D_3=2.42 feet. *C*, Pier with square nose and square tail; channel contraction 50 percent; Q=56.2 cubic feet per second, D_1=3.08 feet, D_3=2.90 feet. *D*, Pier with semicircular nose and tail; channel contraction 50 percent; Q=56.3 cubic feet per second, D_1=2.75 feet, D_3=2.66 feet.



FLOW PAST PIERS SET AT ANGLE WITH CURRENT.

Piers of length four times width, and with semicircular nose and semicircular tail. *A*, Pier at 10-degree angle with flow; $Q=75.6$ cubic feet per second, $D_1=2.09$ feet, $D_3=2.04$ feet. *B*, Pier at 20-degree angle with flow; $Q=68.7$ cubic feet per second, $D_1=2.23$ feet, $D_3=2.17$ feet.





A, Making velocity traverses around pier in testing channel. *B*, Twin piers being lowered into testing canal.

5. Twin-cylinder piers without diaphragm.
6. Twin-cylinder piers with diaphragm.
7. Triangular nose and tail of 90° angle.
8. Triangular nose and tail of 90° angle with 1:12 batter.
9. Semicircular nose and lens-shaped tail.
10. Lens-shaped nose and semicircular tail.
11. Semicircular nose and semicircular tail with 1:24 batter on ends and sides; web one-third thickness of nose and tail at flood-stage level.
12. Semicircular nose and semicircular tail with 1:24 batter on ends and sides; web one-third thickness of nose and tail at flood-stage level; quarter round fillets in recesses at tail.
13. Semicircular nose and semicircular tail with 1:24 batter on ends and sides; web one-third thickness of nose and tail at flood-stage level; quarter-round fillets in recesses at tail and triangular-shaped fillets in recesses at nose.
14. Semicircular nose and semicircular tail; web same thickness as nose and tail; 1:24 batter all around.

The third series of tests was made on a single pier 3.5 feet wide placed in the center of the 10-foot testing canal. Two shapes of noses and tails were tested in this series: (1) Square nose and square tail, and (2) semicircular nose and semicircular tail. The over-all lengths were 7.0 feet.

The fourth series of tests was made on a single pier 5.0 feet wide placed in the center of the 10-foot canal. Two shapes of noses and tails were tested in this series: (1) Square nose and square tail, and (2) semicircular nose and semicircular tail. The over-all lengths were 8.5 feet.

The effect of the length of the pier upon the coefficient was determined by experiments upon piers of 14-inch width with barrels 2 times and 4 times the length of those of the piers upon which the regular tests were run, thus giving ratios of over-all length to width of 7 to 1 and 13 to 1. Only two shapes of noses and tails were tested on these: (1) Square nose and square tail, and (2) semicircular nose and semicircular tail.

In addition to the above experiments, two series of tests were made on a pier placed at angles of 10° and 20° with the current. The pier was 14 inches wide and had semicircular nose and tail.

The loss of head caused by the various set-ups was determined for quantities of flow ranging from about 10 to 160 cubic feet per second. Different depths of flow were obtained for each discharge and for each type of pier by means of an adjustable weir located in the channel downstream from the piers. The depths past the piers ranged from about 0.6 foot to more than 3 feet.

A series of tests were also run in which (1), a constant depth was maintained upstream from the piers, and (2), a constant velocity was maintained upstream from the piers.

The combination of these conditions gave a total of about 2,600 experiments.

In addition to measuring the loss of head for each type of pier for various quantities and depths of flow, an investigation of velocity distribution was made for one type of pier, with 1 discharge and 2 depths of flow. The direction of flow of various filaments of water as well as the elevations of the water surface at the pier site were also obtained for these two tests.

Views of some of the piers tested are shown in plates 1 to 7.

DESCRIPTION OF EXPERIMENTAL PLANT

UNIVERSITY LABORATORY

The hydraulic laboratory of the University of Iowa is located on the west bank of Iowa River south of the university dam. The laboratory provided, in addition to other facilities, a gravity water supply feeding a concrete testing canal 312 feet long, 10 feet wide, and 10 feet deep. At the upstream end of this canal, where it joins the end of the dam, is an electrically operated gate 10 feet wide by 10 feet deep. The dam is 9 feet high, thus insuring a head of from 9 to 10 feet, depending upon the stage of the river, and an ample quantity of water.

MEASURING WEIR

For measuring the quantity of water flowing past the piers, a sharp-crested rectangular weir 10 feet long of the suppressed type was built. The weir was located 61 feet downstream from the head gate. The quantity of water passing over the weir was regulated by raising or lowering the head gate.

Since the water entered the canal under the head gate with a high velocity, a submerged baffle 4 feet high was built on the bottom of the canal immediately downstream from the head gate. This baffle consisted of three 2- by 12-inch planks placed on edge 6 inches apart. Ten feet below the head gate, a baffle of 2- by 4-inch by 10-foot timbers placed horizontally 1 inch apart was constructed. One foot downstream from this baffle, another baffle was built of 2- by 4-inch timbers placed vertically 1 inch apart.

To avoid commotion of the water as it approached the pier, three baffles were installed below the weir. The first of these, located 6 feet from the weir, was built of 2- by 4-inch timbers 10 feet long placed horizontally 1½ inches apart. The next baffle, located 7 feet from the weir, consisted of 2- by 4-inch timbers 4 feet long placed vertically 1½ inches apart. The last baffle, located 10.5 feet from the weir, consisted of oval-shaped timbers placed vertically, the spaces between being 1½ inches close to the upstream face enlarging to 4½ inches wide at the downstream face. This baffle also was 4 feet high. These three baffles had the desired effect of stilling the turbulence of the water. Measurements taken ahead of the piers showed uniform velocity as the water approached the piers.

To determine the head on the weir, a hook gage was placed on the east wall of the canal. A 1½-inch pipe passing through the wall of the canal 15.77 feet upstream from the weir and 10¾ inches above the bottom of the canal was connected to a 15- by 36-inch cylindrical galvanized tank which served as a stilling well over which was mounted the hook gage. Bazin's formula was used to determine the discharge over the weir.

PIER MODELS

Each pier model was mounted as shown in plate 1 in the bottom of the testing canal. Several of the set-ups tested are shown in plates 1 to 7, inclusive.

The pier models were made of wood. For the regular tests, a central section 1.167 feet wide by 3.50 feet long was used for all the piers; to this were attached the different forms of noses and tails, in changing the design. Thus the total lengths of the piers varied somewhat depending upon the shape of the ends.

The central section of the pier model was secured to the floor in the canal some 40 feet downstream from the weir.

PIEZOMETERS AND PIEZOMETER TUBES

The loss of head caused by the piers was measured by means of piezometers instead of the customary stilling wells and hook gages located upstream and downstream from the pier. Thirty-seven piezometer openings spaced throughout a distance of 69 feet were made through the east wall, 4 inches above a level floor built in the bottom of the testing canal. Ten openings spaced 2½ feet apart were placed upstream from the pier, 15 openings spaced 6 inches apart were placed at the site of the pier models, while 12 openings spaced 2½ feet apart were placed downstream from the pier models. Connections were made from the piezometer openings by means of rubber tubing to 1-inch glass tubes 3 feet long attached to white-enameled gage staffs secured to the outside wall of the testing canal. These gage staffs, 3.3 feet long, were graduated with divisions of 0.02 foot, and the markings were such that they could be read to the nearest 0.01 foot with little chance of error.

The depth of flow and water surface gradient upstream and downstream from the piers as well as the depth in the contracted section along the piers were obtained from these piezometers. In addition, several staff gages which were used for check readings were set at various points along both walls of the canal, the zeros of all staffs being set even with the level floor constructed in the canal.

An adjustable weir 6 feet high some 80 feet downstream from the center of the piers was used to regulate the water level downstream from the piers. This weir was hung on hinges and was adjusted by means of a block and tackle.

THEORY OF THE OBSTRUCTION OF BRIDGE PIERS TO FLOW OF WATER

Let figure 1 represent a bridge pier with the water flowing through the contracted area. The following symbols are used:

Q = the quantity of water flowing in volume per second.
D_1 = the mean depth of the water upstream from the nose of the pier at a distance equal to the length of the pier.
D_2 = the mean depth of the stream in the most contracted section of the channel.
D_3 = the mean depth of the water in the channel below the contraction; that is, the depth in the unobstructed channel.
W_1 = the mean width of the channel above the contraction.
W_2 = the mean width of flow at the most contracted section of the channel.
W_3 = the mean width of the channel below the contraction, ordinarily equal to W_1.

V_1 = the mean velocity of the water above the contraction, $= \frac{Q}{W_1 D_1}$.

V_2 = the mean velocity of the water in the most contracted section of the channel $= \frac{Q}{W_2 D_2}$.

V_3 = the mean velocity of the water in the channel below the contraction $= \frac{Q}{W_3 D_3}$, which will ordinarily be equal to $\frac{Q}{W_1 D_3}$.

H_2 = the drop of the water surface at the most contracted section $= D_1 - D_2$.
H_3 = the drop of the water surface in passing through the contraction $= D_1 - D_3$.

g = the acceleration of gravity.
$V_1^2/2g$ = the velocity head of the water above the channel contraction.
$V_2^2/2g$ = the velocity head in the most contracted section of the channel.
$V_3^2/2g$ = the velocity head of the water below the contraction.

α = channel-contraction ratio = $\frac{\text{cross-sectional area of obstructions}}{\text{cross-sectional area of channel}}$.

$\omega = \frac{\text{velocity head below contraction}}{\text{depth of flow below contraction}} = \frac{V_3^2/2g}{D_3}$

K = a pier-shape coefficient to take account of the losses due to friction, impact, eddies, etc. The subscripts D'A, W, N, and R designate D'Aubuisson, Weisbach, Nagler, and Rehbock formulas, respectively.

δ_0 = pier-shape coefficient in Rehbock general bridge-pier formula (see equation 7).

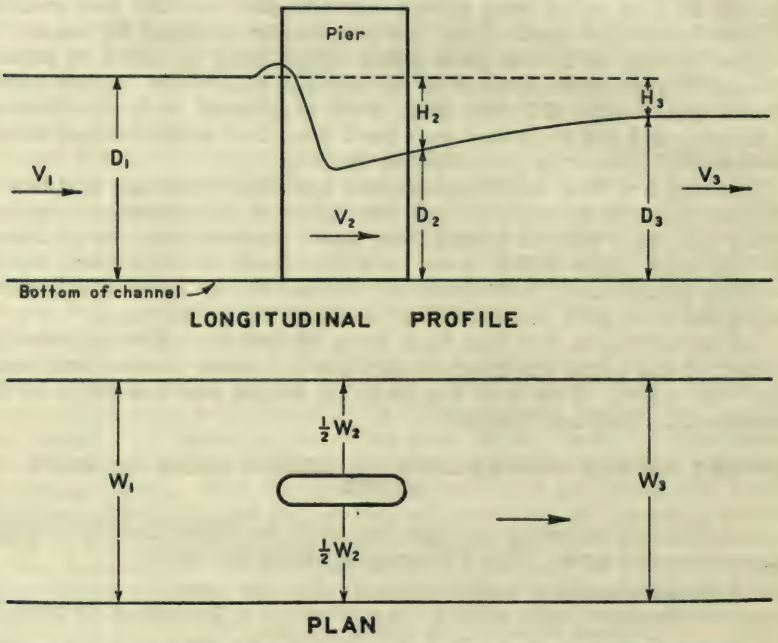


FIGURE 1.—Diagram of bridge pier showing symbols used in formulas: vertical scale exaggerated.

The real backwater height as shown in figure 1 is H_3. The surface drop H_2 in the contracted area is sometimes erroneously called the backwater height.

D'Aubuisson (*3*) probably first advanced the theory that the drop H_2 was merely the difference of the velocity heads for points D_1 and D_2. His formula becomes, by substituting D_1 for (D_2+H_2),

$$H_2 = \frac{Q^2}{2g}\left(\frac{1}{K^2_{D'A} W_2^2 D_2^2} - \frac{1}{W_1^2 D_1^2}\right) \quad (1)$$

in which $K_{D'A}$ is the D'Aubuisson pier-shape coefficient.

The true backwater is not exactly represented by H_2, but ordinarily in practical field installations there will be little difference between H_2 and H_3, and hence little difference between D_2 and D_3.

Therefore, only the values of the D'Aubuisson coefficient using H_3 and D_3 are given. Transposing and rearranging the terms in equation 1, substituting V_1 for Q/W_1D_1, and H_3 and D_3 for H_2 and D_2 and solving for Q, equation 1 for practical use becomes

$$Q=K_{D'A}W_2D_3\sqrt{2g\ H_3+V_1^2} \tag{2}$$

whence

$$K_{D'A}=\sqrt{\frac{Q^2}{2gW_2^2D_3^2(H_3+V_1^2/2g)}} \tag{3}$$

Weisbach (*17, pp. 114–116*) based his formula upon the assumption that the total discharge through the contracted section may be calculated as the sum of two quantities, one quantity consisting of the flow through a submerged orifice of width W_2 and height D_2, and another quantity consisting of the flow over a weir with a crest length of W_1 and a head of H_2. The formula then becomes

$$Q=K_W\sqrt{2g}\left[\frac{2}{3}W_1(H_2+V_1^2/2g)^{3/2}+W_2D_2(H_2+V_1^2/2g)^{1/2}\right] \tag{3-a}$$

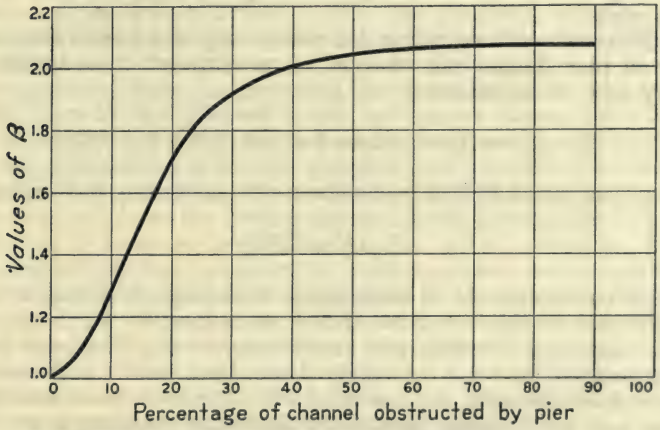


FIGURE 2.—Values of coefficient β in Nagler bridge-pier formula.

Nagler's (*9*) formula is

$$Q=K_NW_2\sqrt{2g}[D_3-\theta V_3^2/2g]\sqrt{H+\beta V_1^2/2g} \tag{4}$$

in which the coefficients θ and β depend upon the conditions at the site of the bridge pier. The coefficient θ is merely a correction coefficient, and the factor $\theta V_3^2/2g$ is intended to correct D_3 to give a smaller depth of flow similar to that at the most contracted section. This coefficient has little effect upon the results obtained when the depth of the stream is several feet or more. In all computations, the value of θ was taken as 0.3. The coefficient β varies with the percentage of channel contraction, the amount of change being greatest for channel contractions between 5 and 30 percent. This coefficient may be obtained from figure 2, prepared by Professor Nagler.

Rehbock (*11*) divides the flow into three classes as follows:

1. Ordinary or "steady" flow, in which the water passes the obstruction with very slight or no turbulence.
2. Intermediate flow, in which the water passing the obstruction displays a moderate degree of turbulence.
3. "Changed" flow, in which the water passing the obstruction becomes "completely" turbulent.

These three classes of flow are defined according to Rehbock by the following equations.

$$\alpha_A = \frac{1}{0.97+21\omega} - 0.13 \tag{5}$$

$$\alpha_B = 0.05 + (0.9 - 2.5\omega)^2 \tag{6}$$

According to Rehbock, the moving water will be included in the first class as long as the obstruction ratio α of the pier site is less than the limiting value in equation 5. When the value of α of the pier site under investigation lies between the values of α_A in formula 5 and α_B in formula 6 the second condition of flow prevails, and when the value of α of the pier site exceeds that given in equation 6 the third condition of flow exists.

The Rehbock (*13*) equation for computing the backwater height, H_3, for all pier shapes in a channel of rectangular cross section with ordinary flow, is as follows:

$$H_3 = [\delta_0 - \alpha(\delta_0 - 1)](0.4\alpha + \alpha^2 + 9\alpha^4)(1 + 2\omega)V_3^2/2g \tag{7}$$

A simple equation for bridge backwater is, according to Rehbock (*11*)

$$H_3 = K_R \alpha V_3^2/2g \tag{8}$$

It is probable that the D'Aubuisson, Weisbach, and Nagler formulas apply only to the first class of flow as defined by Rehbock.

Determinations of bridge-pier coefficients for the Weisbach formula were attempted, but the extremely discordant results indicated that this formula is theoretically unsound and the effort was abandoned.

There are many other backwater formulas mentioned in foreign publications on hydraulics, of which Tolman (*15*), in reviewing all formulas and methods of which he knew in 1917, mentions as most prominent those of Dupuit, Eytelwein, Flament, Freytag-D'Aubuisson, Gauthey, Heinemann, Hofmann, Lesbros, Mehmcke, Montanari, Navier, Ruhlmann, Tolkmitt, Turazza, and Wex. For reasons of economy, coefficients were not determined for these formulas which are seldom mentioned in English texts on hydraulics.

TEST PROCEDURE

Tests were run with quantities of flow ranging from 10 to 160 cubic feet per second, and with depths of flow, D_3, from 0.6 foot to 3.3 feet.

The experiments were begun with a head of about 0.4 foot of water discharging over the measuring weir, followed by tests with successive increases of about 0.1 foot in head on the measuring weir until the greatest possible quantity was obtained. Different stages of flow at

the site of the pier for each head on the measuring weir were obtained by means of the adjustable weir downstream from the pier.

In part of the tests the adjustable weir was set at a definite position while a complete set of runs for the pier set-up was obtained with various heads on the measuring weir. After the desired head on the measuring weir was obtained, the observer first read the hook gage above the weir; then he obtained readings to the nearest 0.01 foot on the 37 piezometers along the wall of the canal, and recorded the depth of the water in the channel as shown by the various staff gages set along the inside wall of the canal. A reading was then taken on the weir hook gage to see if the water level had varied. This process was repeated for each head on the weir. The adjustable weir was then set at another position and another series of runs obtained.

In the majority of the experiments the pier models were placed in the dry testing channel and water allowed to flow through the canal past the piers. The difference between the water surfaces immediately upstream and downstream from the pier was called the backwater. To preclude any criticism of the method used in determining the backwater, an extensive series of experiments was run in 1929 in which water was permitted to flow through the unobstructed testing channel and the water-surface profile was obtained, after which the pier models were set in the channel and the water-surface elevations again obtained. The difference between the elevation of the water surface upstream from the piers and the elevation of the water surface with no piers in the channel is the backwater caused by the piers. The results obtained from the two methods of testing were identical.

The second method of testing was slow and expensive, considerable time being spent in raising the heavy pier models (weighing considerably over a ton) from the testing channel and lowering them back into the channel to measure the backwater. In order to conduct the tests by this method it was necessary to build a special device (plate 8, *B*) which would set the piers exactly in place in the channel. For these reasons, in the great majority of tests as stated above, the piers were built in the channel before the water was allowed to enter.

Ordinarily six tests were obtained for each head on the weir, two in each class of flow as defined by Rehbock. Thus it was possible to obtain a comparison of Rehbock's formula, considering his classes of flow, with D'Aubuisson's and Nagler's. For each quantity of flow one test was run in which the adjustable weir was lowered to its limit. For most discharges with this position of the adjustable weir, critical velocity was obtained at the site of the pier. This condition, however, will seldom occur at bridge locations in natural streams.

Levels were taken on the weir hook gage, and on all piezometer gages during the progress of the experiments, to see that these instruments did not change in elevation.

EFFECT OF SHAPE OF PIER ON COEFFICIENT

The relative amount of obstruction a bridge pier offers to the flow of water may be expressed in the form of a pier-shape coefficient. The coefficient depends upon the backwater formula used. In the D'Aubuisson, Weisbach, and Nagler formulas the pier-shape coefficient varies directly with the discharge. For a given amount of backwater, depth of flow, and channel contraction, if the pier-shape coefficient is increased 10 percent the discharge is increased 10 percent.

The coefficient is, in some measure, an index number of the hydraulic efficiency of the pier.

The effect of the shape of pier upon the coefficient is shown in table 1. This table is a summary of the average values of the coefficients for the different classes of flow for the formulas of D'Aubuisson, Nagler, and Rehbock.

TABLE 1.—*Bridge-pier coefficients as determined for different shapes of piers*

[Standard piers, length four times width, in testing channel 10 feet wide]

Formula	Class 1 flow		Class 2 flow		Class 3 flow		Average coefficient for classes 1 and 2[2]	Average coefficient for classes 1, 2, and 3[2]
	Tests averaged	Coefficient	Tests averaged	Coefficient	Tests averaged	Coefficient		
SQUARE NOSES AND TAILS; ONE AND TWO PIERS[1]								
	Number		*Number*		*Number*			
D'Aubuisson-$K_D'_A$	99	1.018	70	0.946	47	0.952	0.988	0.980
Nagler-K_N	99	.871	70	.858	47	1.113	.866	.920
Rehbock-δ_0	99	4.78	70	6.82		[3]	5.62	
Rehbock-K_R	99	3.11	70	5.07	47	6.68	3.92	4.52
SEMICIRCULAR NOSES AND TAILS; ONE AND TWO PIERS								
D'Aubuisson-$K_D'_A$	31	1.079	30	1.001	26	1.034	1.041	1.038
Nagler-K_N	31	.934	30	.905	26	1.278	.920	1.027
Rehbock-δ_0	31	3.35	30	5.50		[3]	4.40	
Rehbock-K_R	31	2.08	30	4.09	26	5.33	3.07	3.75
CONVEX NOSES AND TAILS; ONE AND TWO PIERS								
D'Aubuisson-$K_D'_A$	36	1.089	33	1.057	30	1.042	1.074	1.064
Nagler-K_N	36	.949	33	.931	30	1.251	.940	1.034
Rehbock-δ_0	36	2.68	33	4.36		[3]	3.49	
Rehbock-K_R	36	1.48	33	3.11	30	5.34	2.35	3.26
LENS-SHAPED NOSES AND TAILS; ONE AND TWO PIERS								
D'Aubuisson-$K_D'_A$	37	1.051	23	1.033	30	1.076	1.044	1.055
Nagler-K_N	37	.952	23	.932	30	1.387	.944	1.092
Rehbock-δ_0	37	3.55	23	4.79		[3]	4.02	
Rehbock-K_R	37	2.05	23	3.37	30	5.17	2.56	3.43
90° TRIANGULAR NOSES AND TAILS WITHOUT BATTER; TWO PIERS								
D'Aubuisson-$K_D'_A$	37	1.065	45	0.985	58	0.997	1.021	1.011
Nagler-K_N	37	.887	45	.883	58	1.145	.885	.993
Rehbock-δ_0	37	3.54	45	5.51		[3]	4.62	
Rehbock-K_R	37	2.48	45	4.27	58	5.72	3.46	4.40
90° TRIANGULAR NOSES AND TAILS WITH BATTER 1:12; TWO PIERS								
D'Aubuisson-$K_D'_A$	28	1.109	30	1.005	23	0.960	1.055	1.028
Nagler-K_N	28	.906	30	.894	23	.986	.900	.924
Rehbock-δ_0	28	2.64	30	4.99		[3]	3.86	
Rehbock-K_R	28	1.89	30	3.90	23	5.76	2.93	3.74

See footnotes at end of table.

TABLE 1.—*Bridge-pier coefficients as determined for different shapes of piers*—Continued

SEMICIRCULAR NOSES AND LENS-SHAPED TAILS; TWO PIERS

Formula	Class 1 flow		Class 2 flow		Class 3 flow		Average coefficient for classes 1 and 2[2]	Average coefficient for classes 1, 2, and 3[2]
	Tests averaged	Coefficient	Tests averaged	Coefficient	Tests averaged	Coefficient		
	Number		*Number*		*Number*			
D'Aubuisson-$K_{D'A}$	32	1.152	36	1.018	28	0.991	1.081	1.045
Nagler-K_N	32	.928	36	.901	28	1.068	.913	.958
Rehbock-δ_0	32	1.88	36	4.67		[3]	3.36	
Rehbock-K_R	32	1.41	36	3.69	28	5.53	2.62	3.47
SEMICIRCULAR NOSE AND TAIL; PIER AXIS AT 10° ANGLE WITH CURRENT; ONE PIER (COEFFICIENT INCLUDES EFFECT OF ANGLE WITH CURRENT)								
D'Aubuisson-$K_{D'A}$	25	1.032	28	0.949	21	0.929	0.988	0.971
Nagler-K_N	25	.936	28	.919	21	.979	.927	.942
Rehbock-δ_0	25	3.80	28	8.21		[3]	6.13	
Rehbock-K_R	25	2.22	28	5.49	21	7.84	3.95	5.05
SEMICIRCULAR NOSE AND TAIL; PIER AXIS AT 20° ANGLE WITH CURRENT; ONE PIER (COEFFICIENT INCLUDES EFFECT OF ANGLE WITH CURRENT)								
D'Aubuisson-$K_{D'A}$	38	0.943	38	0.865	34	0.879	0.904	0.896
Nagler-K_N	38	.876	38	.861	34	.957	.869	.896
Rehbock-δ_0	38	8.22	38	13.29		[3]	10.75	
Rehbock-K_R	38	4.69	38	8.78	34	10.28	6.74	7.83
LENS-SHAPED NOSES AND SEMICIRCULAR TAILS; TWO PIERS								
D'Aubuisson-$K_{D'A}$	36	1.162	38	1.042	34	1.007	1.100	1.071
Nagler-K_N	36	.932	38	.912	34	1.081	.922	.972
Rehbock-δ_0	36	1.73	38	4.11		[3]	2.95	
Rehbock-K_R	36	1.31	38	3.26	34	5.17	2.31	3.21
TWIN-CYLINDER PIERS WITHOUT DIAPHRAGMS; 1 AND 2 PIERS								
D'Aubuisson-$K_{D'A}$	79	0.991	69	0.957	40	0.985	0.976	0.977
Nagler-K_N	79	.892	69	.894	40	1.054	.893	.927
Rehbock-δ_0	79	6.13	69	7.26		[3]	6.66	
Rehbock-K_R	79	3.62	69	5.07	40	5.76	4.30	4.61
TWIN-CYLINDER PIERS WITH DIAPHRAGMS; 1 AND 2 PIERS								
D'Aubuisson-$K_{D'A}$	65	0.966	61	0.975	44	0.991	0.986	0.987
Nagler-K_N	65	.907	61	.905	44	1.041	.906	.941
Rehbock-δ_0	65	5.99	61	6.85		[3]	6.41	
Rehbock-K_R	65	3.48	61	4.75	44	5.56	4.10	4.48
SEMICIRCULAR NOSE AND SQUARE TAIL; 1 PIER								
D'Aubuisson-$K_{D'A}$	20	1.014	4	0.940			1.002	
Nagler-K_N	20	.941	4	.923			.938	
Rehbock-δ_0	20	4.45	4	8.44			5.12	
Rehbock-K_R	20	2.53	4	5.52			3.03	
SQUARE NOSE AND SEMICIRCULAR TAIL; 1 PIER								
D'Aubuisson-$K_{D'A}$	19	0.976	6	0.926			0.964	
Nagler-K_N	19	.912	6	.912			.912	
Rehbock-δ_0	19	6.30	6	9.26			7.01	
Rehbock-K_R	19	3.55	6	5.96			4.13	

See footnotes at end of table.

TABLE 1.—*Bridge-pier coefficients as determined for different shapes of piers*—Continued

Formula	Class 1 flow		Class 2 flow		Class 3 flow		Average coefficient for classes 1 and 2[2]	Average coefficient for classes 1, 2, and 3[2]
	Tests averaged	Coefficient	Tests averaged	Coefficient	Tests averaged	Coefficient		
53° TRIANGULAR NOSE AND SEMICIRCULAR TAIL; 1 PIER								
	Number		*Number*		*Number*			
D'Aubuisson-$K_D'_A$	19	1.024	7	0.978			1.012	
Nagler-K_N	19	.945	7	.950			.947	
Rehbock-δ_0	19	4.06	7	6.44			4.70	
Rehbock-K_R	19	2.29	7	4.21			2.81	
90° TRIANGULAR NOSE AND SEMICIRCULAR TAIL; 1 PIER								
D'Aubuisson-$K_D'_A$	20	1.027	6	0.957			1.011	
Nagler-K_N	20	.948	6	.933			.944	
Rehbock-δ_0	20	3.90	6	7.48			4.72	
Rehbock-K_R	20	2.22	6	4.82			2.82	
60° TRIANGULAR NOSE AND SEMICIRCULAR TAIL; 1 PIER								
D'Aubuisson-$K_D'_A$	23	1.007	7	0.983			1.001	
Nagler-K_N	23	.932	7	.952			.937	
Rehbock-δ_0	23	4.83	7	6.34			5.18	
Rehbock-K_R	23	2.69	7	4.15			3.03	
SEMICIRCULAR NOSES AND TAILS, WEB SAME THICKNESS AS NOSES AND TAILS; BATTER 1:24 ALL AROUND; 2 PIERS								
D'Aubuisson-$K_D'_A$	21	1.155	22	0.993	22	0.972	1.072	1.038
Nagler-K_N	21	.930	22	.887	22	1.030	.908	.949
Rehbock-δ_0	21	1.80	22	5.29		[3]	3.58	
Rehbock-K_R	21	1.36	22	4.12	22	5.83	2.77	3.81
SEMICIRCULAR NOSES AND TAILS CONNECTED BY WEB; BATTER 1:24 ON ENDS AND SIDES OF NOSES AND TAILS; WEB THICKNESS ONE-THIRD OF PIER WIDTH AT FLOOD LEVEL; 2 PIERS								
D'Aubuisson-$K_D'_A$	34	1.020	43	0.951	36	0.959	0.982	0.975
Nagler-K_N	34	.863	43	.865	36	.988	.864	.904
Rehbock-δ_0	34	4.51	43	6.36		[3]	5.54	
Rehbock-K_R	34	3.10	43	4.92	36	5.91	4.12	4.69
SEMICIRCULAR NOSES AND TAILS WITH 1:24 BATTER, CONNECTED BY WEB WITH QUARTER-ROUND FILLETS AT TAIL; 2 PIERS								
D'Aubuisson-$K_D'_A$	23	1.087	22	0.989	22	0.962	1.038	1.014
Nagler-K_N	23	.897	22	.886	22	.953	.892	.912
Rehbock-δ_0	23	3.05	22	5.35		[3]	4.17	
Rehbock-K_R	23	2.17	22	4.15	22	5.56	3.14	3.93
SEMICIRCULAR NOSES AND TAILS WITH 1:24 BATTER, CONNECTED BY WEB WITH FILLETS QUARTER-ROUND AT TAIL AND TRIANGULAR AT NOSE; 2 PIERS								
D'Aubuisson-$K_D'_A$	24	1.082	26	0.977	22	0.954	1.027	1.005
Nagler-K_N	24	.895	26	.881	22	.922	.888	.898
Rehbock-δ_0	24	3.15	26	5.71		[3]	4.48	
Rehbock-K_R	24	2.24	26	4.45	22	5.55	3.39	4.05

[1] Channel contractions for all set-ups in this table were 11.7 percent for 1 pier and 23.3 percent for 2 piers.

[2] Average for all tests in the 2 or 3 classes, not average of the determinations for separate classes shown in preceding columns.

[3] δ_0 was not computed for class 3 flow.

α	SS	RR	CC	LL	TT	T–T
11.7 L = 4W	.908	.941	.954	.953	.898	.907
23.3 L = 4W	.864 (.861)	.927 (.923)	.943	.943	.883	.904
23.3				$P_{90°}$ $P_{90°}$ .887	$P_{90°B}$ $P_{90°B}$ .906	RL .928
35 L = 2W	.867	.986				
50 L = 1.7W	.888	1.108				
11.7 L = 4W		10° .936				
11.7 L = 4W		20° .876				
23.3 L = 7W	.855	.916				
23.3 L = 13W	.843	.901				

Contraction of
Width of pier
Total length o
Ratio of leng

Squ
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FIGURE 3.—Diagrammatic summary of Iowa test results showing Nagler bridge-pier coe
were determined by Nagler in his Michigan

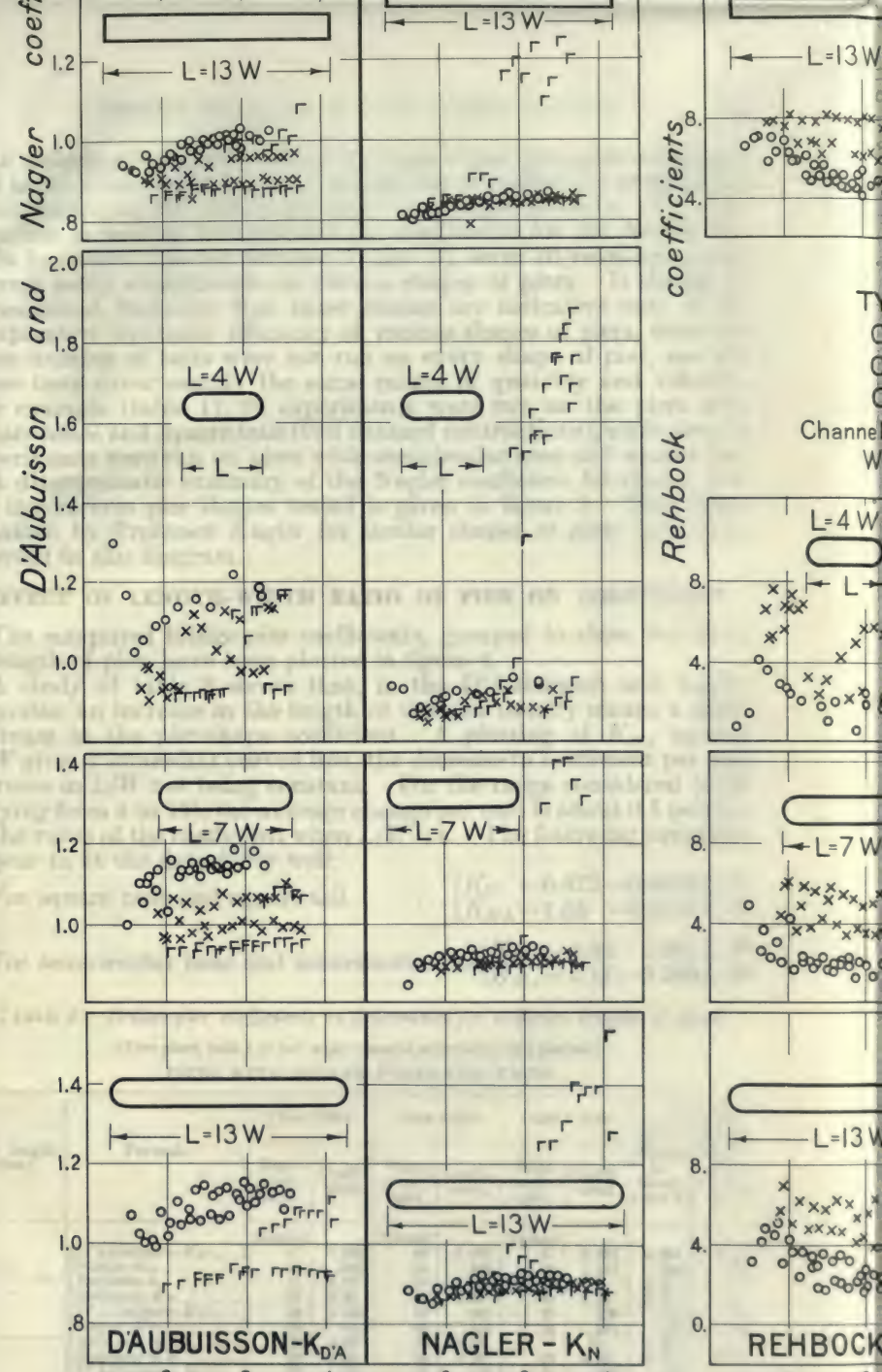

FIGURE 4.—Effect of length of pier upon the coefficients in bridge-pier formulas. Piers of lengths
both with square ends and with semicircular ends.

In making a study of the effect of shape of pier upon the coefficient, and hence upon the discharge, it is desirable to confine the preliminary investigation to the values obtained in a single formula. For convenience in making comparisons the coefficients for the Nagler formula have been selected because Nagler (*9*), some 20 years ago, made a great many experiments on various shapes of piers. It should be remembered, however, that these studies are indicative only of the comparative hydraulic efficiency of various shapes of piers, since the same number of tests were not run on every shape of pier, nor did these tests cover exactly the same ranges of quantity and velocity. For example (table 1), 99 experiments were run on the piers with square noses and square tails (two channel contractions), while only 20 experiments were run on piers with semicircular nose and square tail.

A diagrammatic summary of the Nagler coefficient for class 1 flow for the various pier shapes tested is given in figure 3. The values obtained by Professor Nagler for similar shapes of piers have been inserted in this diagram.

EFFECT OF LENGTH-WIDTH RATIO OF PIER ON COEFFICIENT

The computed bridge-pier coefficients, grouped to show the effect of length of pier, have been plotted in figure 4.

A study of table 2 shows that, in the D'Aubuisson and Nagler formulas, an increase in the length of the pier usually means a slight decrease in the pier-shape coefficient. A plotting of $K_{D'A}$ against L/W gives a somewhat curved line, the decrease in coefficient per unit increase in L/W not being constant. For the range considered (L/W varying from 4 to 13), the average change per unit is about 0.5 percent of the value of the coefficient when $L/W=4$. The following equations appear to fit the data fairly well:

For square nose and square tail $\begin{cases} K_N = 0.873 - 0.0023 L/W \\ K_{D'A} = 1.05 - 0.0052 L/W \end{cases}$

For semicircular nose and semicircular tail $\begin{cases} K_N = 0.94 - 0.003 L/W \\ K_{D'A} = 1.17 - 0.006 L/W \end{cases}$

TABLE 2.—*Bridge-pier coefficients as determined for different lengths of piers*

(Two piers, each 1.17 feet wide; channel contraction 23.3 percent)

PIERS WITH SQUARE NOSES AND TAILS

Pier length (feet)	Formula	Class 1 flow		Class 2 flow		Class 3 flow		Average coefficient for classes a and 2 [1]	Average coefficient for classes 1, 2, and 3 [1]
		Tests averaged	Coefficient	Tests averaged	Coefficient	Tests averaged	Coefficient		
		Number		*Number*		*Number*			
4.67	D'Aubuisson-$K_{D'A}$	81	1.029	64	0.950	47	0.952	0.994	0.984
	Nagler-K_N	81	.864	64	.854	47	1.113	.859	.921
	Rehbock-δ_0	81	4.37	64	6.46		[2]	5.29	
	Rehbock-K_R	81	2.97	64	4.88	47	6.68	3.81	4.51
8.17	D'Aubuisson-$K_{D'A}$	28	1.003	29	.935	23	.926	.968	.956
	Nagler-K_N	28	.855	29	.856	23	.971	.855	.889
	Rehbock-δ_0	28	4.92	29	6.83		[2]	5.89	
	Rehbock-K_R	28	3.39	29	5.26	23	6.62	4.34	5.00
15.17	D'Aubuisson-$K_{D'A}$	30	.981	30	.919	30	.920	.950	.940
	Nagler-K_N	30	.843	30	.847	30	.972	.845	.887
	Rehbock-δ_0	30	5.52	30	7.22		[2]	6.37	
	Rehbock-K_R	30	3.76	30	5.55	30	6.80	4.66	5.37

[1] Average for all tests in the 2 or 3 classes, not average of the determinations for separate classes shown in preceding columns.

[2] δ_0 was not computed for class 3 flow.

TABLE 2.—*Bridge-pier coefficients as determined for different lengths of piers*—Con.

PIERS WITH SEMICIRCULAR NOSES AND TAILS

Pier length (feet)	Formula	Class 1 flow		Class 2 flow		Class 3 flow		Average coefficient for classes 1 and 2	Average coefficient for classes 1, 2, and 3
		Tests averaged	Coefficient	Tests averaged	Coefficient	Tests averaged	Coefficient		
		Number		*Number*		*Number*			
4.67	D'Aubuisson-$K_{D'A}$	15	1.150	23	1.014	26	1.034	1.068	1.054
	Nagler-K_N	15	.927	23	.896	26	1.278	.908	1.058
	Rehbock-δ_0	15	2.03	23	4.84		[2]	3.73	
	Rehbock-K_R	15	1.52	23	3.81	26	5.33	2.91	3.89
8.17	D'Aubuisson-$K_{D'A}$	26	1.128	29	1.021	23	.980	1.072	1.045
	Nagler-K_N	26	.916	29	.904	23	1.011	.910	.939
	Rehbock-δ_0	26	2.28	29	4.58		[2]	3.49	
	Rehbock-K_R	26	1.67	29	3.62	23	5.44	2.69	3.50
15.17	D'Aubuisson-$K_{D'A}$	34	1.096	37	.996	31	.975	1.044	1.023
	Nagler-K_N	34	.901	37	.890	31	1.036	.895	.938
	Rehbock-δ_0	34	2.90	37	5.19		[2]	4.09	
	Rehbock-K_R	34	2.07	37	4.07	31	5.74	3.11	3.91

[2] δ_0 was not computed for class 3 flow.

With the Rehbock formula, not only is the variation in δ_0 larger for a given change in L/W, but it is in the opposite direction, increasing for an increase in length, as is of course to be expected since δ_0 increases with the height of backwater. It should be noted, however, that Rehbock's experiments showed δ_0 to have a minimum when L/W equalled 4.5, and then to increase again for lengths shorter than that, which could not be verified from these tests since no ratios less than 4 were used.

When δ_0 was plotted against L/W and a straight line drawn as nearly as possible through the points, the resulting equations were:

For square nose and square tail, $\delta_0=3.94+0.12\ L/W$.

For semicircular nose and semicircular tail, $\delta_0=1.48+0.11\ L/W$.

The corresponding equations given by Rehbock are:

For square nose and square tail, $\delta_0=3.10+0.12\ L/W$.

For semicircular nose and semicircular tail, $\delta_0=1.27+0.12\ L/W$.

The agreement as to the effect of increase in length of pier is very satisfactory, but there is a surprising difference in the coefficient L for the square-ended pier.

A plotting of K_R against L/W gives unsatisfactory results, the curve being convex downward in the case of the square ends; and convex upward, with a minimum value of K_R when $L/W=7$, in the case of the round ends. Therefore, no further attempt is made to discuss the effect of variations in length on the Rehbock simplified formula. Rehbock does not seem to have treated it either.

All of the above is based on values for class 1 flow only.

For most practical cases, considering the ratios of length to width ordinarily used in bridge piers, the results of these experiments seem to indicate that this variation with length can be neglected.

EFFECT OF CHANNEL CONTRACTION ON COEFFICIENT

In figure 5 the computed bridge-pier coefficients have been plotted in a manner to show the effect of the degree of channel contraction.

A study of the mathematical structure of the four backwater for-

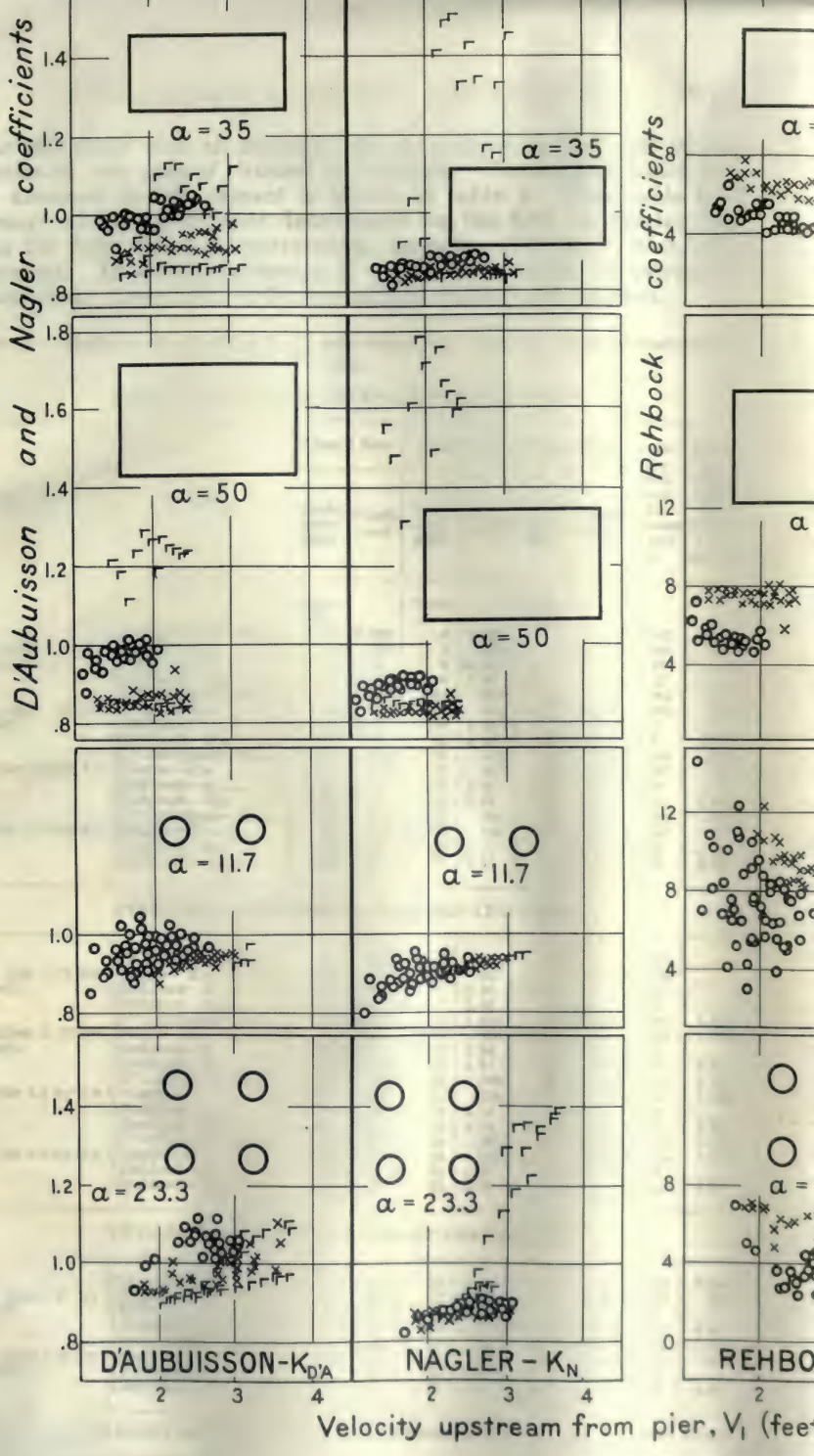

FIGURE 5.—Effect of channel cont

Velocity upstream from pier (ft/sec)

mulas will show that an attempt has been made in each one of the formulas to take care of channel contraction. The success which has been attained in this respect is shown in table 3. This table is a summary of the coefficients determined for the four backwater formulas for four channel contractions; namely, 11.7, 23.3, 35.0, and 50 percent. In an ideal formula K would be constant for piers of a certain shape regardless of the amount of channel contraction.

TABLE 3.—*Bridge-pier coefficients as determined for different channel-contraction ratios*

PIERS WITH SQUARE NOSES AND SQUARE TAILS

Channel contraction ratio	Formula	Class 1 flow		Class 2 flow		Class 3 flow		Average coefficient for classes 1 and 2 [1]	Average coefficient for classes 1, 2, and 3 [1]
		Tests averaged	Coefficient	Tests averaged	Coefficient	Tests averaged	Coefficient		
		Number		*Number*		*Number*			
0.117 (1 pier 1.17 by 4.67 feet.	D'Aubuisson—$K_{D'A}$	18	0.969	6	0.903			0.952	
	Nagler—K_N	18	.908	6	.900			.906	
	Rehbock—δ_0	18	6.63	6	10.62			7.62	
	Rehbock—K_R	18	3.71	6	7.00			4.53	
0.233 (2 piers 1.17 by 4.67 feet).	D'Aubuisson—$K_{D'A}$	81	1.029	64	.950	47	.952	.994	.984
	Nagler—K_N	81	.864	64	.854	47	1.113	.859	.921
	Rehbock—δ_0	81	4.37	64	6.46		[2]	5.29	
	Rehbock—K_R	81	2.97	64	4.88	47	6.68	3.81	4.51
0.35 (1 pier 3.5 by 7.0 feet).	D'Aubuisson—$K_{D'A}$	28	.999	29	.918	26	.958	.958	.957
	Nagler—K_N	28	.867	29	.847	26	1.062	.857	.921
	Rehbock—δ_0	28	4.79	29	6.36		[2]	5.59	
	Rehbock—K_R	28	4.26	29	6.01	26	6.62	5.15	5.61
0.5 (1 pier 5.0 by 8.5 feet).	D'Aubuisson—$K_{D'A}$	23	.971	27	.856	25	1.034	.909	.951
	Nagler—K_N	23	.888	27	.830	25	1.214	.857	.976
	Rehbock—δ_0	23	5.42	27	7.52		[2]	6.55	
	Rehbock—K_R	23	6.79	27	9.81	25	7.76	8.42	8.20

PIERS WITH SEMICIRCULAR NOSES AND TAILS

0.117 (1 pier 1.17 by 4.67 feet).	D'Aubuisson—$K_{D'A}$	16	1.012	7	.958			.996	
	Nagler—K_N	16	.941	7	.937			.940	
	Rehbock—δ_0	16	4.57	7	7.66			5.51	
	Rehbock—K_R	16	2.63	7	5.02			3.35	
0.233 (2 piers 1.17 by 4.67 feet).	D'Aubuisson—$K_{D'A}$	15	1.150	23	1.014	26	1.034	1.068	1.054
	Nagler—K_N	15	.927	23	.896	26	1.278	.908	1.058
	Rehbock—δ_0	15	2.03	23	4.84		[2]	3.73	
	Rehbock—K_R	15	1.52	23	3.81	26	5.33	2.91	3.89
0.35 (1 pier 3.5 by 7.0 feet).	D'Aubuisson—$K_{D'A}$	30	1.228	32	1.069	28	1.036	1.146	1.112
	Nagler—K_N	30	.986	32	.936	28	1.158	.961	1.022
	Rehbock—δ_0	30	1.73	32	3.63		[2]	2.71	
	Rehbock—K_R	30	1.81	32	3.64	28	5.39	2.75	3.57
0.50 (1 pier 5.0 by 8.5 feet).	D'Aubuisson—$K_{D'A}$	24	1.312	24	.991	24	1.118	1.152	1.140
	Nagler—K_N	24	1.108	24	.936	24	1.317	1.022	1.120
	Rehbock—δ_0	24	1.65	24	4.94		[2]	3.30	
	Rehbock—K_R	24	2.81	24	6.85	24	6.37	4.83	5.35

TWIN-CYLINDER PIERS WITHOUT DIAPHRAGM

0.117 (1 pier 1.17 by 4.67 feet).	D'Aubuisson—$K_{D'A}$	51	0.957	32	0.929	4	0.943	0.946	0.946
	Nagler—K_N	51	.898	32	.915	4	.963	.904	.907
	Rehbock—δ_0	51	7.44	32	9.28		[2]	8.15	
	Rehbock—K_R	51	4.17	32	6.05	4	6.47	4.89	4.96
0.233 (2 piers 1.17 by 4.67 feet).	D'Aubuisson—$K_{D'A}$	28	1.055	37	.982	36	.990	1.013	1.005
	Nagler—K_N	28	.883	37	.875	36	1.080	.879	.943
	Rehbock—δ_0	28	3.74	37	5.51		[2]	4.75	
	Rehbock—K_R	28	2.61	37	4.22	36	5.67	3.53	4.29

[1] Average for all tests in the 2 or 3 classes, not average of the determinations for separate classes shown in preceding columns.

[2] δ_0 was not computed for class 3 flow.

TABLE 3.—*Bridge-pier coefficients as determined for different channel-contraction ratios*—Continued

TWIN-CYLINDER PIERS WITH DIAPHRAGM

Channel contraction ratio	Formula	Class 1 flow		Class 2 flow		Class 3 flow		Average coefficient for classes 1 and 2 [1]	Average coefficient for classes 1, 2, and 3 [1]
		Tests averaged	Coefficient	Tests averaged	Coefficient	Tests averaged	Coefficient		
		Number		*Number*		*Number*			
0.117 (1 pier 1.17 by 4.67 feet).	D'Aubuisson—$K_{D'A}$	51	0.969	30	0.932	7	0.935	0.955	0.953
	Nagler—K_N	51	.907	30	.919	7	.953	.911	.915
	Rehbock—δ_0	51	6.83	30	9.10	-------	(2)	7.67	-------
	Rehbock—K_R	51	3.86	30	5.96	7	6.68	4.64	4.80
0.233 (2 piers 1.17 by 4.67 feet).	D'Aubuisson—$K_{D'A}$	14	1.094	31	1.017	37	1.000	1.041	1.023
	Nagler—K_N	14	.904	31	.893	37	1.056	.897	.969
	Rehbock—δ_0	14	2.93	31	4.66	-------	(2)	4.12	-------
	Rehbock—K_R	14	2.11	31	3.58	37	5.35	3.12	4.13
PIERS WITH CONVEX NOSES AND TAILS									
0.117 (1 pier 1.17 by 4.67 feet).	D'Aubuisson—$K_{D'A}$	22	1.034	11	0.967	-------	-------	1.012	-------
	Nagler—K_N	22	.954	11	.938	-------	-------	.948	-------
	Rehbock—δ_R	22	3.48	11	7.13	-------	-------	4.70	-------
	Rehbock—K_R	22	1.97	11	4.60	-------	-------	2.85	-------
0.233 (2 piers 1.17 by 4.67 feet).	D'Aubuisson—$K_{D'A}$	14	1.178	22	1.100	30	1.042	1.130	1.090
	Nagler—K_N	14	.943	22	.928	30	1.251	.934	1.078
	Rehbock—δ_0	14	1.44	22	2.97	-------	(2)	2.37	-------
	Rehbock—K_R	14	1.15	22	2.36	30	5.34	1.89	3.46
PIERS WITH LENS-SHAPED NOSES AND TAILS									
0.117 (1 pier 1.17 by 4.67 feet).	D'Aubuisson—$K_{D'A}$	32	1.032	10	0.978	-------	-------	1.019	-------
	Nagler—K_N	32	.953	10	.947	-------	-------	.952	-------
	Rehbock—δ_0	32	3.84	10	6.59	-------	-------	4.50	-------
	Rehbock—K_R	32	2.18	10	4.27	-------	-------	2.68	-------
0.233 (2 piers 1.17 by 4.67 feet).	D'Aubuisson—$K_{D'A}$	5	1.166	13	1.075	30	1.076	1.100	1.085
	Nagler—K_N	5	.943	13	.920	30	1.387	.927	1.214
	Rehbock—δ_0	5	1.61	13	3.42	-------	(2)	2.92	-------
	Rehbock—K_R	5	1.28	13	2.67	30	5.17	2.29	4.09

[2] δ_0 was not computed for class 3 flow.

The coefficients for piers with square and with semicircular noses and tails for the four channel contractions and for class 1 flow are shown graphically in figure 6.

An examination of the coefficients for the piers with semicircular noses and semicircular tails shows that in all the formulas the coefficients vary considerably for different channel contractions. The D'Aubuisson coefficient increases with an increase in channel contraction. The Rehbock coefficient δ_0, decreases with an increase in channel contraction until at a contraction of 23.3 percent, it becomes fairly constant. The Nagler coefficient is practically the same for channel contractions of 11.7 and 23.3 percent, but increases for contractions greater than 23.3 percent.

In an examination of the coefficients for the piers with square noses and square tails it appears that the Nagler coefficient is practically constant for all channel contractions up to 50 percent. The D'Aubuisson coefficient was highest with the channel contraction of 23.3 percent and was practically alike with channel contractions of 11.7 and 50 percent. On the other hand, the Rehbock coefficient,

δ_0, decreased with an increase in channel contraction up to a contraction of 23.3 percent and then increased again.

A study of the coefficients for the twin-cylinder piers with and without diaphragms and for the piers with convex and lens-shaped noses and tails (table 3) shows that for the 11.7 and 23.3 percent channel contractions the Rehbock coefficient, δ_0, without exception decreased with an increase in channel contraction whereas the D'Aubuisson coefficient increased with an increase in channel contraction. On the other hand, the Nagler coefficient was practically constant regardless of the shape of the pier.

These same tendencies are noted in a study of the average coefficients for both class 1 and class 2 flows.

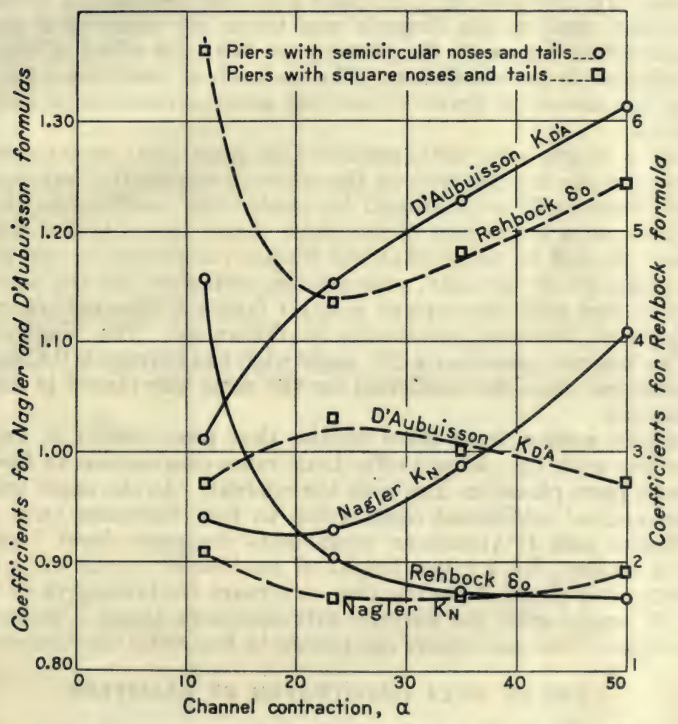

FIGURE 6.—Variation in pier coefficient with channel contraction for class 1 flow.

The difficulties which engineers have experienced in the past in obtaining reasonable results in backwater computations have been due largely to the fact that they used a pier-shape coefficient obtained for channel contractions other than those which prevailed in their problems. These data show the necessity of selecting a coefficient which is applicable to the problem under consideration. On the other hand, the limited amount of data available for large-percentage channel contractions (35 to 50 percent), involving tests on only two shapes of single piers, indicates the need of additional investigation before the tendencies indicated in figure 6 may be considered fully established.

Since the majority of bridge openings have channel contractions less than 23 percent, it would seem that the Nagler formula is best suited for practical use because coefficients derived for it appear to show the least variation below that percentage of channel contraction.

EFFECT ON COEFFICIENT OF SETTING PIERS AT ANGLE WITH CURRENT

It is reasonable to expect more backwater when piers are placed at an angle with the current than when placed in line with the current. No definite information exists, however, on the additional backwater caused by such setting. Experiments were run on a pier with a semicircular nose and semicircular tail placed at two angles with the current, namely, 10° and 20°. In each case, the percentage of channel contraction used in the formula was taken the same as if the pier were placed in line with the current, so that the effect of the angle was reflected in the coefficient. The individual coefficients for these set-ups are shown in figure 7, and the average coefficients are given in table 1.

Since a single pier with semicircular nose and semicircular tail was used in the experiments on the effect of angularity, any comparison of these coefficients should be made with coefficients obtained from tests on a single pier of the same shape placed in line with the current. It will be noted that the Nagler coefficient for the pier set at an angle of 10° is 0.936, whereas the coefficient for the same pier placed in line with the current is 0.941 (table 3, channel contraction 11.7 percent), showing practically no difference. The Nagler coefficient for the pier placed at a 20° angle with the current is 0.876, about 7 percent less than the coefficient for the same pier placed in line with the current.

It would appear from these studies that piers placed at angles of 10° or less with the current offer little more obstruction to flow than the same piers placed in line with the current. As the angle increases the amount of additional obstruction to flow increases until at 20° the Nagler and D'Aubuisson coefficients decrease about 7 percent. That is to say, for a given height of backwater, depth of flow, and percentage of channel contraction, a stream containing piers placed at a 20° angle with the current will discharge about 7 percent less water than if the same piers are placed in line with the current.

USE OF DATA ILLUSTRATED BY EXAMPLES

These experiments have made available coefficients for use in hydraulic formulas for computing either the backwater due to the obstruction of piers to the flow of water or, knowing the backwater height, the quantity of water passing through a bridge opening. If either quantity of flow or backwater height is definitely known, it is possible to compute the other with a reasonable degree of accuracy. This procedure can best be illustrated by practical examples.

EXAMPLE 1

A stream discharging at flood stage 45,000 cubic feet per second has a cross-sectional area of flow at the bridge site as shown in figure 8. The piers have semicircular noses and semicircular tails, the ends and

Velocity spectrum from pier, V

sides are built with a batter of one-half inch per foot of height; ratio of width to length is 1 to 4. The total cross-sectional area of flow is

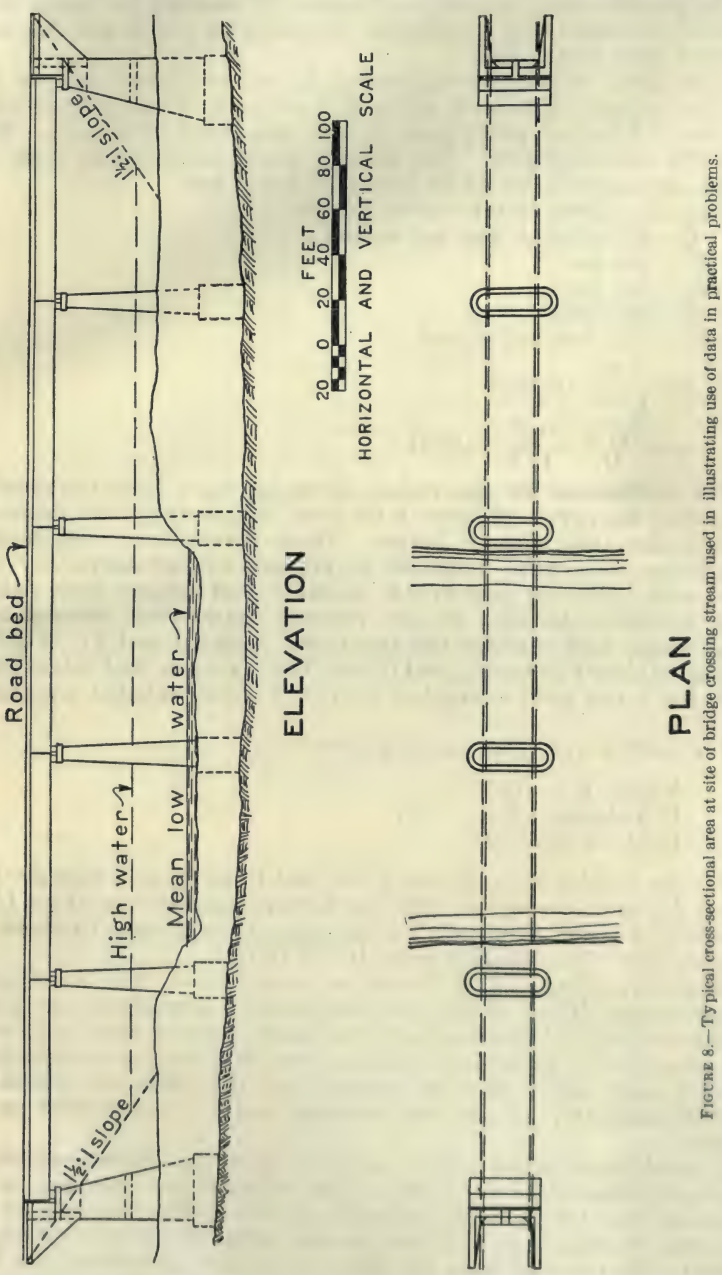

FIGURE 8.—Typical cross-sectional area at site of bridge crossing stream used in illustrating use of data in practical problems.

7,560 square feet, of which the piers take up 720 square feet. Thus the channel contraction is 9.5 percent. It is desired to compute the

backwater which may be expected to occur at this bridge site for the flood of 45,000 cubic feet per second.

The problem may be computed either by treating the entire flood opening as a unit or by treating the channel area proper and the bank overflow area separately.

In the first method of computation V_3 will be 45,000/7,560 or 5.95 feet per second. The total width of flood area, W_1 may be taken as 390 feet. The four piers, each 10 feet wide, take up 40 feet. Thus $W_2=390-40=350$ feet. The average depth downstream from the bridge opening, D_3, would be 7,560/390=19.4 feet.

Thus the known factors are as follows:

$Q=45{,}000$ cubic feet per second
$W_1=390$ feet
$W_2=350$ feet
$D_3=19.4$ feet
$V_3=5.95$ feet per second

$$\alpha=\frac{720}{7{,}560}=0.0952$$

$$\omega=\frac{V_3^2/2g}{D_3}=\frac{0.55}{19.4}=0.0284$$

The coefficients for the various formulas have been obtained by extending the curves of figure 6 for piers with semicircular noses and semicircular tails without batter. These curves were used because insufficient data were available to prepare similar curves for such piers with batter as used in this example, and because such data as were available (for 23.3 percent channel contraction) showed quite close comparison between the two types (tables 1 and 3). Figure 6 applies to class 1 flow only, and it is within that class that this example falls, for ω has been computed as 0.0284 which satisfies equation 5 (p. 10).

The coefficients, then, are as follows:

Nagler $K_N=0.95$
D'Aubuisson $K_{D'A}=0.97$
Rehbock $\delta_0=5.50$

For the Nagler formula (no. 4) we find from figure 2 that $\beta=1.24$. Using K_N as 0.95 and θ as 0.30, the formula may be solved for H_3 by assuming a value to obtain V_1, and then recomputing to check the assumption. The solution gives $H_3=0.16$ feet.

Similarly, using the coefficients as found above, the D'Aubuisson formula gives $H_3=0.19$ foot and the Rehbock formula $H_3=0.14$ foot.

Since velocity of flow depends upon slope, depth of flow, vegetation, etc., the velocity will not be uniform throughout such a cross-sectional area of flow, and it may be argued that the backwater should be figured separately for the main channel and for the overflow on the banks.

It would seem reasonable to expect a somewhat higher velocity in the main channel of the stream than through the openings on the banks of the stream since the depth of flow in the former is 28 feet and the average depth of flow in the latter is about 10 feet. A velocity downstream from the piers of 6.5 feet per second has been assumed for the main channel and to make the quantity of flow check, the velocity on the banks will have to be about 4.46 feet per second.

The channel contraction for the main channel is 9.2 percent and for the banks is about 10.4 percent.

Thus the known factors for the main channel are as follows:

Q=35,940 cubic feet per second
W_1=200 feet
W_2=180 feet
D_3=27.65 feet
V_3=6.5 feet per second

$$\alpha=\frac{\text{area occupied by piers}}{\text{total area}}=\frac{510}{5,530}=0.092$$

$$\omega=\frac{V_3^2/2g}{D_3}=\frac{0.657}{27.65}=0.0237$$

β in the Nagler formula=1.24

Using the same bridge-pier coefficients for the Nagler and D'Aubuisson formulas as before but changing Rehbock's to 5.60 (fig. 6) we get for main stream the following backwater:

By the Nagler formula, K_N=0.95, H_3=0.14.
By the D'Aubuisson formula, $K_{D'A}$=0.97, H_3=0.21.
By the Rehbock formula (no. 7), δ_0=5.60, H_3=0.16.

The known factors for the remainder of the opening (taken as a whole) are as follows:

Q=9,060 cubic feet per second
W_1=190 feet
W_2=170 feet
D_3=10.68 feet
V_3=4.46 feet per second

$$\alpha=\frac{\text{area occupied by piers}}{\text{total area}}=\frac{210}{2,030}=0.1035.$$

$$\omega=\frac{V_3^2/2g}{D_3}=\frac{0.309}{10.68}=0.02894$$

β in the Nagler formula=1.27.

Using coefficients from figure 6, we get for the area of flow on the banks the following backwater:

By the Nagler formula, K_N=0.93, H_3=0.07.
By the D'Aubuisson formula, $K_{D'A}$=0.99, H_3=0.09.
By the Rehbock formula (no. 7), δ_0=5.0, H_3=0.08.

These results represent an unstable condition. That is to say, assuming a level surface on a transverse section upstream from the piers, the water immediately below the piers is shown to be about 0.10 foot lower in the center of the channel than along the banks. This may be true just below the piers, but the water will immediately become level transversely as the water passes downstream. About four times as much water has been assumed to flow in the main channel as over the banks and the final average drop-down would therefore seem to be an average of that in the main channel and that on the banks, weighted in proportion to the quantity of water flowing in each section. The final average would about equal the drop-down computed by treating the entire cross-sectional area as a unit.

EXAMPLE 2

A highway bridge 350 feet long, built across a river valley was subjected to a flood. At the crest of the flood, the drop-down in the water surface at the bridge opening was found to be an average of 0.30 foot for the seven openings. The six piers, each 8 feet wide with semicircular nose and semicircular tail, are spaced 50 feet center to center. The average depth of flow immediately downstream from the opening was 8 feet. It is desired to compute the discharge through the opening.

The values of the known factors are as follows:

W_1=350 feet
W_2=302 feet
H_3=0.30 foot
D_3=8.0 feet
α=0.137

The Nagler formula using θ=0.30, β=1.45, and K_N=0.93, gives a discharge of 22,300 cubic feet per second.

The D'Aubuisson formula with $K_{D'A}$=1.05, gives a discharge of 22,800 cubic feet per second.

The Rehbock formula with δ_0=3.20, gives a discharge of 23,200 cubic feet per second.

SUMMARY AND CONCLUSIONS

The bridge-pier formulas most commonly used in the United States are D'Aubuisson's, Nagler's, Weisbach's, and Rehbock's. The discordant results obtained with the Weisbach formula show it to be theoretically unsound.

None of the above formulas give for a certain shape of pier a constant coefficient for all channel contractions. This factor is of vital importance and is the reason for the inconsistent results obtained in the past by engineers attempting to solve problems involving backwater from bridge piers. The majority of such problems concern cases having channel contractions of less than 20 percent.

As long as the velocities are low enough to keep within what Rehbock calls class 1 flow, any one of the three formulas will give results close enough for practical purposes, if the proper coefficient is used. This coefficient varies with the channel contraction as well as the pier shape, as is shown by table 3 and figure 6. Proper values for channel contractions of less than 11.7 percent were not determined, and for most of the pier shapes they also are not determined for contractions greater than 23.3 percent. However, most backwater problems fall within this range, but as the D'Aubuisson and Rehbock formulas give quite different coefficients at 11.7 percent than they do at 23.3 percent, and as no points are known between them, the shape of the curve remains undetermined. This objection does not apply to the Nagler formula because there is little difference in the coefficients for 11.7 percent and 23.3 percent, and the tests of the square and semicircular shapes indicate that a constant average value can be used throughout the range. The Nagler formula also applies through Rehbock's class 2 and into the beginning of class 3. The other two formulas do not apply at these higher velocities (except

with continually varying coefficients), and thus fail in the most serious cases of "heading-up" due to extreme floods.

The conclusions to be drawn from the experiments on bridge piers of various shapes and sizes may be summarized as follows:

The height of the backwater due to bridge piers varies directly as the depth of the unobstructed channel.

Certain formulas heretofore proposed give approximately correct results for ordinary velocities when the proper coefficients are used, but they do not hold for extremely high velocities. The coefficients for these formulas as determined by these tests are listed in tables 1 and 3.

For the lower velocities (class 1 flow) the more efficient shapes are lens-shaped nose and tail, lens-shaped nose and semicircular tail, semicircular nose and lens-shaped tail, convex nose and tail, and semicircular nose and tail. Since the latter is the only one tested with piers obstructing a large percentage of the channel, the tests made at Iowa City were not sufficient to distinguish between these shapes.

Twin-cylinder piers either with or without connecting diaphragms, piers with 90° triangular noses and tails, and piers with recessed webs are less efficient hydraulically than those just mentioned, and piers with square noses and tails are least efficient.

The addition of batter to the ends of piers slightly increases their hydraulic efficiency.

Increasing the length of a pier from 4 times the width to 13 times the width has comparatively little effect on its hydraulic efficiency. In some cases it increases it and in some cases decreases it. The optimum ratio of pier length to width probably varies with the velocity and is generally between 4 and 7.

Placing the piers at an angle with the current has an insignificant effect on the amount of backwater if the angle is less than 10°. Placing the piers at an angle of 20° or more with the current materially increases the amount of backwater, the increase depending upon the quantity of flow, the depth, and the channel contractions.

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1865. An encyclopaedia of civil engineering, historical, theoretical, and practical. 1752 pp., illus. London.

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1878. Manuel de l'ingenieur des ponts et chaussees . . . [1] v. Paris.

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1801. Handbuch der mechanik und der hydraulik.

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1926. Von der bewegung des wassers und den dabei auftretenden kräften . . . 228 pp., illus. Berlin.

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1920. EXPERIMENTS ON THE FLOW OF WATER THROUGH CONTRACTIONS IN AN OPEN CHANNEL. Amer. Soc. Civ. Engin. Trans. (1919–20) 83: 1149–1219, illus.
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1918. OBSTRUCTION OF BRIDGE PIERS TO THE FLOW OF WATER. Amer. Soc. Civ. Engin. Trans. 82: [334]–395, illus.
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1917. BETRACHTUNGEN UEBER ABFLUSS, STAU UND WALZENBILDUNG . . . 114 pp., illus. Berlin.
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1919. ZUR FRAGE DES BRÜCKENSTAUES. Zentbl. Bauverwaltung 39: 197–200, illus.
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1921. BRÜCKENSTAU UND WALZENBILDUNG. Bauingenieur 2: 341–347, illus.
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1921. VERFAHREN ZUR BESTIMMUNG DES BRÜCKENSTAUES BEI REIN STRÖMENDEM WASSERDURCHFLUSS. Bauingenieur 2: 603–609, illus.
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1926. DAS FLUSSBAULABORATORIUM DER TECHNISCHEN HOCHSCHULE IN KARLSRUHE. Ch. VI, DIE WASSERBAULABORATORIEN EUROPAS, pp. 106–115, illus. Berlin.
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1917. ÜBER DIE BERECHNUNG DES BRÜCKENSTAUES, 120 pp. Prague.
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1847–48. PRINCIPLES OF THE MECHANICS OF MACHINERY AND ENGINEERING. 2 v., illus. London.
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1926. FLOW OF WATER THROUGH CULVERTS. Iowa Univ. Studies Engin. Bull. 1, 128 pp., illus.

ANNOTATED REFERENCES RELATING TO BRIDGE PIERS AS CHANNEL OBSTRUCTIONS

AKADEMISCHEN VEREIN HÜTTE, Berlin.
1925–28. "HÜTTE" DES INGENIEURS TASCHENBUCH. Aufl. 25, neubearb., 4 v., illus. Berlin.
Gives formula for computing backwater, formula really being D'Aubuisson's. Mentions Rehbock's and Krey's work.

BLANCHARD, A. H., ed.
1919. AMERICAN HIGHWAY ENGINEERS' HANDBOOK. 1,658 pp., illus. New York.
Quotes formula given in Merriman's Hydraulics.
States coefficient K may be taken as 0.9 for piers with round ends, and 0.8 for triangular cutwaters.

BLIGH, W. G.
1910. THE PRACTICAL DESIGN OF IRRIGATION WORKS. Ed. 2, rev. and enl., 449 pp., illus. New York.
Suggests treating obstruction as a submerged overfall using Castel coefficient of 0.66.

BOX, T.
1902. PRACTICAL HYDRAULICS. A SERIES OF RULES AND TABLES FOR THE USE OF ENGINEERS, ETC., ETC. Ed. 13, 80 pp., illus. London.
States that "the head lost by a stream in passing through a bridge is principally that due to velocity alone, the length of the channel being in most cases so short as to have little influence on the discharge."

BUSQUET, R.
1906. A MANUAL OF HYDRAULICS. Trans. by A. H. Peake. 312 pp., illus. London.
Quotes D'Aubuisson's formula and gives values of K as 0.85 for pier with square nose and 0.95 for pier with nose tapered to narrow edge forming sharp quoins.

DELACHENAL and LEFORT, R.
1911. OBSERVATIONS FAITES SUR LA SEINE A PARIS PENDANT LA GRANDE CRUE DE 1910. Ann. Ponts et Chaussées (9) 4:11–53, illus.
Shows diagrams of many bridges over the Seine during flood of 1910, giving location of eddies, water surface curves, etc.

DURAND-CLAYE, A.
1873. HYDRAULIQUE—EXPERIENCES SUR LES AFFOUILLEMENTS. Ann. Ponts et Chaussées (5) 5:467–483.
Gives data on rectangular, round, and triangular piling and makes comparison of the three forms.

ENGELS, H.
1894. SCHUTZ VON STROMPFEILERFUNDAMENTEN GEGEN UNTERSPÜLUNG. Ztschr. Bauwesen 44: 407–415, illus.

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1914. HANDBUCH DES WASSERBAUES, FÜR DAS STUDIUM UND DIE PRAXIS. 2 v., illus. Leipzig and Berlin.
Gives formula

$$Q=KW_2\sqrt{2g}\left\{\frac{2}{3}\left[\left(H_2+\frac{V_1^2}{2g}\right)^{3/2}-\left(\frac{V_1^2}{2g}\right)^{3/2}\right]+D_2\sqrt{H_2+\frac{V_1^2}{2g}}\right\}$$

and values of the pier-shape coefficient K as 0.90 for 90-degree triangular nose, 0.95 for 60-degree triangular nose, 0.95 for semicircular nose, and 0.97 for convex nose.

FLAMANT, A. A.
1909. HYDRAULIQUE. Ed. 3, pp. 277–278. Paris.
Gives four shapes of piers. Quotes writings of A. Durand-Claye. Shows pier with triangular nose and semicircular tail as suitable form.

FORCHHEIMER, P.
1930. HYDRAULIK. Ed. 3, 595 pp., illus. Leipzig and Berlin.
Discusses writings of Eytelwein, Gauthey, Navier, Sonne, Montanari, and Tolman. Goes into experimental work of Rehbock in considerable detail. Calls attention to Rehbock's findings that the least backwater is developed when, for the same shape of pier, the length of the pier is from three to five times its width. Quotes Rehbock's formula and gives some of Rehbock's coefficients for various shapes of piers.

FOWLER, C. E.
1920. A PRACTICAL TREATISE ON ENGINEERING AND BUILDING FOUNDATIONS, INCLUDING SUB-AQUEOUS FOUNDATIONS. Ed. 4, rev. and enl., 531 pp., illus. New York.
Mentions Bossut's mathematical solution which showed that the nose should be 90-degree triangular, and Dubuat's mathematical solution which showed the faces of the pier nose should be convex. Describes in some detail Cresy's experiments made with models being 15 centimeters in thickness, and shows forms of piers tested.

FREEMAN, J. R., ed.
1929. HYDRAULIC LABORATORY PRACTICE. . . 868 pp., illus. New York.
Comprising a translation, revised to 1929, of Die Wasserbaulaboratorien Europas which was published in 1926 by Verein Deutscher Ingenieure, and including also descriptions of other European and American laboratories and notes on the theory of experiments with models.

GIBSON, A. H.
1925. HYDRAULICS AND ITS APPLICATIONS. Ed. 3, 801 pp., illus. New York.

Gives the following formula for loss of head due to bridge piers:

$$H_2=\frac{Q^2}{2g}\left(\frac{1}{K^2W_2^2D_2^2}-\frac{1}{W_1^2D_1^2}\right)$$

The value of K, he says, varies from 0.95 (Eytelwein) for a pier with pointed cutwaters to 0.85 for a pier with square ends or cutwaters.

GILLMORE, Q. A.

1882. OBSTRUCTION TO RIVER DISCHARGE BY BRIDGE PIERS. Van Nostrand's Engin. Mag. 26: [441]–452.

Discusses effect on flow of railroad bridge crossing Chemung River in New York. In formula $V=C\sqrt{RS}$ assumes C equals 100 on bed of main stream and 84.3 on shallow flats.

HAWES, C. G., and KAHAI, H. S.

1929. REPORT ON EXPERIMENTS CARRIED OUT AT THE KARACHI MODEL TESTING STATION ON A MODEL OF A FLUMED REGULATOR. Bombay Pub. Works Dept. Tech. Paper no. 31, 7 pp., illus.

Experiments were made on a flumed regulator having one and two piers in the throat of the regulator. Six different shapes of noses and seven different shapes of tails were tested with the single pier, while three noses and seven tails were tested with the two piers. The channel at the pier site was 1.61 feet wide and the single piers were 0.18 foot wide, contracting the channel a little more than 11 percent. The barrels of the piers were about 2.5 feet long exclusive of the nose and tail, making the ratio of L/W somewhat over 14. When the two piers were used, each one was made 0.09 foot wide thus the two piers caused the same channel contraction as the single pier 0.18 foot wide.

The 1:5 cutwater was found so little better, in regard to loss of head, than the curved nose (with radius double the pier width) that it would not pay to use 1:5 noses. The shape of the tail appeared to have little effect on the amount of loss of head (contradictory to the findings in Technical Paper No. 29). Two piers in the channel caused very little more loss than a single pier with like cut and ease water.

HOOL, G. A., and KINNE, W. S., editors, assisted by BAKER, H. S.

1923. FOUNDATIONS, ABUTMENTS, AND FOOTINGS. Compiled by a staff of specialists. 414 pp., illus. New York.

HOUK, I. E.

1918. CALCULATION OF FLOW IN OPEN CHANNELS. Miami Conservancy Dist. Tech. Repts., pt. 4, 283 pp., illus.

Discusses calculation of discharge from measurements at contracted openings. Uses Bernouilli's theorem to derive a formula which can be used to compute drop if the other factors are known. Formula derived is same as d'Aubuisson's. States friction loss at contracted section may be considerable and should be determined.

Gives Merriman's formula and says this is an erroneous drop-off formula. The part to which Houk takes exception is the first term in the formula which considers part of the water as passing over a weir. Houk says, "The objections to this method are two: first, the essence of a weir is a crest which contracts the cross-section of the moving stream, and such a contraction is the absolutely essential basis of the weir formula. At the place chosen for the calculation, upstream from the drop-off, there is no crest and no contraction. Second, the water moving in the upper surface layers at points upstream from the drop-off, passes at the point of contraction through the area treated as a submerged orifice. This water is an essential part of that flowing through the submerged orifice, and is necessary to help keep up the supply moving through the orifice with the increased velocity due to the drop-off."

HOWDEN, A. C.
1868. FLOODS IN THE NERBUDDA VALLEY: WITH REMARKS ON MONSOON FLOODS IN INDIA GENERALLY. Inst. Civ. Engin. [England] Minutes Proc. (1867–68) 27: 218–273, illus.

Gives data on backwater at Towah Viaduct during floods of 1865 and 1866 and at Gunjal Viaduct in 1866, as being respectively 10, 15, and 3. 5 feet. Cross sections of stream and profiles of the water surface are given, but no velocities were measured. Unwin used one of these cases as illustration of backwater due to bridge piers in articles on Hydraulics in ninth and eleventh editions of Encyclopedia Britannica, but inadvertently took a velocity measured in 1864 as being that for 1865.

HUTTON, W. R.
1882. ON THE DETERMINATION OF THE FLOOD DISCHARGE OF RIVERS AND OF THE BACKWATER CAUSED BY CONTRACTIONS. Amer. Soc. Civ. Engin. Trans. 11: 211–241, illus.

Discusses case of New York, Lackawanna & Western Railway *v.* New York, Lake Erie & Western Railway where Erie Railroad objected to the proposed bridge piers of the Lackawanna Railroad in Chemung River. There was a great discrepancy in amount of backwater which proposed bridge would cause. Mentions Dupuit's, Debauve's, and Gauthey's formulas.

HINDERKS, A.
1928. GRUNDSTRÖMUNG UND GESCHIEBEBEWEGUNG AN UMFLOSSENEN STROMPFELIERN. Bautechnik 6: 133–135, illus.

INGLIS, C. C., and HAWES, C. G., with REID, J. S., JOGLEKAR, D. V., aud KALAKKAR, H. V.
1929. NOTE ON EXPERIMENTS CARRIED OUT WITH VARIOUS DESIGNS OF PIERS AND SILLS IN CONNECTION WITH THE LLOYD BARRAGE AT SUKKUR. Bombay Pub. Works Dept. Tech. Paper No. 29, 55 p., illus.

Numerous tests made on piers with various shapes of noses and tails, the pier models being one forty-eighth of the full size. States that loss of head caused by piers is composed (1) impact loss, (2) eddy loss, and (3) friction loss. These losses are affected not only by the shape of the nose and tail but also by the length of the piers. States that for normal conditions, noses and tails with equilateral arcs of circles are good and semicircular noses and tails are probably as good.

JACKSON, L. D'A.
1875. HYDRAULIC MANUAL AND STATISTICS. Ed. 3, London.

Gives table showing for various stream velocities the amount of backwater caused by different percentages of channel contraction. Table computed from Dubuat formula,

$$H_3=\left(\frac{V^2}{K^2 2g}+S\right)\left[\left(\frac{A}{a}\right)^2-1\right]$$

in which

A and a are the normal and reduced sectional areas; S is the sine of the hydraulic slope of the river; and K is the experimental coefficient. In most cases S is less than 0.0001 and may be neglected; then when $K=0.96$ the formula becomes

$$H_3=0.0169V^2\left[\left(\frac{A}{a}\right)^2-1\right]$$

KEUTNER, C.
1932. STRÖMUNGSVORGÄNGE AN STROMPFEILERN VON VERSHCIEDENEN GRUNDRISSFORMEN UND IHRE EINWIRKUNG AUF DIE FLUSSSOHLE. ERMITTLUNG DER ZWECKMÄSSIGSTEN GRUNDRISSFORM UND DER WIRKSAMEN KOLKABWEHR. Bautechnik. 10: 161–170, illus.

KING, H. W.
1929. HANDBOOK OF HYDRAULICS FOR THE SOLUTION OF HYDRAULIC PROBLEMS. Ed. 2, 523 pp., illus. New York.

Discusses the loss of head caused by piers and abutments. Mentions Nagler's experiments and shows pier shape found to be efficient.

KING, H. W., and WISLER, C. O.
1922. HYDRAULICS. 237 pp., illus. New York.

KREY, H.
1919. BERECHNUNG DES STAUES INFOLGE VON QUERCHNITT VER ENGUNGEN. Zentbl. Bauverwaltung 39: 472–475, illus.

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1923. DER WIDERSTAND VON EINBAUTEN IN FLÜSSEN UND ANDEREN OFFENEN GERINNEN AUF DAS STRÖMENDE WASSER. Bautechnik 1: [415]–416, illus.

MCCULLOUGH, C. B.
1929. ECONOMICS OF HIGHWAY BRIDGE TYPES. 246 pp., illus. Chicago.
Discusses minimum spacing of piers for the purpose of (1) keeping within a predetermined limit of backwater height during extreme flood flow; (2) keeping flood currents below a certain critical velocity because of erosive tendencies.

MERRIMAN, M.
1914. HYDRAULICS. Ed. 9, 565 pp., illus. New York.
Discusses formula considering discharge as consisting of two parts, first that passing over a weir of breadth W_1 under a head H_3, and second that passing through the submerged orifice of breadth W_2 and height D_2 under the head H_3.

$$Q=C\sqrt{2g}\left[\frac{2}{3}W_1\left(H_3+\frac{V_1^2}{2g}\right)^{3/2}+W_2D_2\left(H_3+\frac{V_1^2}{2g}\right)^{1/2}\right]$$

MOLESWORTH, G. L., and MOLESWORTH, H. B.
1931. POCKET-BOOK OF USEFUL FORMULAE & MEMORANDA FOR CIVIL AND MECHANICAL ENGINEERS. Edited by A. P. Thurston. Ed. 30, rev. and enl., 935 pp., illus. London and New York.
Gives the following formula for rise of water due to obstructions in rivers:

$$R=\left(\frac{V^2}{58.6}+0.05\right)\left[\left(\frac{A}{a}\right)^2-1\right]$$

in which
A=sectional area of river unobstructed, in feet.
a=sectional area of river at obstruction, in feet.
V=velocity previous to obstruction, in feet per second.

NEVILLE, J.
1875. HYDRAULIC TABLES, COEFFICIENTS, AND FORMULAS. Ed. 3, pp. 141–144. London.
Apparently treats the discharge through a contraction as consisting of two parts. States that quantity of water passing through the lower depth, D_2, is equal to

$$KW_2D_2\sqrt{2gH_2}$$

and the quantity of water overflowing through H_2 equals

$$\frac{2}{3}KW_2H_2\sqrt{2gH_2}$$

hence the total discharge through the contracted section becomes

$$Q=KW_2\sqrt{2gH_2}\left(D_2+\frac{2}{3}H_2\right)$$

When the velocity of approach is considerable, or when $V_1^2/2g$ becomes a large portion of H_2, its effect must not be neglected. In this case, as before, the discharge through the depth D_2 is equal to

$$KW_2D_2\sqrt{2g(H_2+V_1^2/2g)}$$

and the discharge through the depth H_2 equal to

$$\frac{2}{3}KW_2\sqrt{2g}[(H_2+V_1^2/2g)^{3/2}-(V_1^2/2g)^{3/2}]$$

and hence the total discharge becomes

$$Q=KW_2\sqrt{2g}\left\{D_2(H_2+V_1^2/2g)^{1/2}+\frac{2}{3}[(H_2+V_1^2/g)^{3/2}-(V_1^2/2g)^{3/2}]\right\}$$

For square ended piers, K equals 0.6; when noses are obtuse $K=0.7$, and when curved or acute $K=0.8$.

SCHOKLITSCH, A.
1930. DER WASSERBAU; EIN HANDBUCH FÜR STUDIUM UND PRAXIS. [1] v., illus., Wien.
Discusses Rehbock's work and gives Rehbock's formula for computing backwater.

STRECK, O.
1924. AUFGABEN AUS DEM WASSERBAU, 362 pp., illus. Berlin.
Gives the formula

$$Q=K_1W_2(D_1-D_2)\sqrt{2g\left(H_3+\frac{V_1^2}{2g}\right)}+\frac{2}{3}K_2W_2\sqrt{2g}\left[\left(H_3+\frac{V_1^2}{2g}\right)^{3/2}-\left(\frac{V_1^2}{2g}\right)^{3/2}\right]$$

and works out a problem.
Uses $K_1=K_2=0.90$ for "die stumpfwinkligen Pfeiler Kopfe setzen wir."

TIMONOFF, V. E.
'1927. VERSUCHE ÜBER DIE ANORDNUNG DER STROMPFEILER BEI NEBENEINANDER STEHENDEN BRÜCKEN Abhandl. St. Petersburger (Leningrader) Pamphlet 5. (1927.)
(Cited by John R. Freeman, ed., in Hydraulic Laboratory Practice, 1929; p. 366.)

TRAUTWINE, J. C.
1909. THE CIVIL ENGINEER'S POCKET-BOOK. Rev. by J. C. Trautwine, Jr., and J. C. Trautwine, 3d. Ed. 19, 1257 pp., illus. New York.
Gives no formulas; merely quotes table (with many corrections) from Nicholson's Architecture. Knowing the original stream velocity and the proportion of area of the original waterway occupied by the obstruction, the head of water produced at the obstruction is given for piers with upstream ends rounded or pointed. Nicholson says that if the piers are square-ended, head will be increased about 50 percent. Trautwine states subject is extremely intricate and admits of no precise solution.

WADDELL, J. A. L.
1916. BRIDGE ENGINEERING. 2 v., illus. New York.
"The amount of backing up or increase of head can be ascertained by considering the discharge between the piers as composed of two elements, viz., the discharge through a submerged orifice, having a width equal to the distance between the piers and a depth equal to that below them, and a flow over a weir of length equal to the distance between the piers and a head equal to the difference in depths above and below them."

WEYRAUCH, R.
1930. HYDRAULISCHES RECHNEN . . . Aufl. 6, neubeart. und verm. von A. Strobel, 370 pp., illus., Stuttgart.
Gives D'Aubuisson's formula and quotes values of coefficients for different shapes of piers.

WILLIAMS, C. C.
1922. THE DESIGN OF MASONRY STRUCTURES AND FOUNDATIONS. 555 pp., illus. New York.
Quotes the Eytelwein formula and gives values for coefficient of contraction.

APPENDIX

ENERGY METHOD OF COMPUTING "HEADING-UP" DUE TO PIERS

A paper [4] by Fred C. Scobey, gives a method for locating the water surface through constrictions, based somewhat on the work of Koch (*7*) who developed a graphical method of determining backwater heights which, however, disregarded friction and pier shape and gave results appreciably different from test measurements. Their method suggests that the backwater resulting from piers might be computed without the aid of laboratory tests or pier-shape coefficients. In order to discuss this question, a brief statement of the method will be necessary [5].

Using the same notation as before (pp. 7–8) and $q=\frac{Q}{W}$,

$$V=\frac{Q}{WD}=\frac{q}{D} \text{ and } \frac{V^2}{2g}=\frac{q^2}{2gD^2}$$

$$\omega=\frac{V^2 2g}{D}=\frac{q^2}{2gD^3} \text{ or } \frac{q^2}{2g}=D^3\omega \tag{9}$$

It is well known that the critical depth in the unobstructed channel occurs when $\omega=\frac{1}{2}$, and that the maximum discharge for any given total energy head is $q_c=\sqrt{gD^3}$. But if an obstruction is introduced into the channel, reducing the width from W to $(1-\alpha)W$, the unit-width discharge in the contracted section will be $q_2=\frac{q_3}{1-\alpha}$, and the maximum q_3 for any given total energy head will be $(1-\alpha)q_2$ when q_2 is critical, or $(1-\alpha)\sqrt{g}D_2^{3/2}$. But when the flow through the contracted section is critical, D_2 will be two-thirds of the total energy head. Neglecting for the moment any energy loss, the total energy head is equal to

$$D_3+\frac{V_3^2}{2g}=D_3+\omega D_3=D_3(1+\omega)$$

When critical velocity exists at D_2.

$$D_2=\frac{2}{3}D_3(1+\omega)$$

$$D_2^3=\frac{8}{27}D_3^3(1+\omega)^3$$

and the maximum q_3 will be given by the formula

$$q_3^2=(1-\alpha)^2q_2^2=(1-\alpha)^2gD_2^3=(1-\alpha)^2g\frac{8}{27}D_3^3(1+\omega)^3$$

But from (9), $q_3^2=2g\omega D_3^3$. Equating these values of q_3^2 and solving we get

$$\frac{\omega_L}{(1+\omega_L)^3}=\frac{4}{27}(1-\alpha)^2 \tag{10}$$

where ω_L indicates the "limiting value" of ω, which would cause critical flow between the piers. Equation (10) is plotted in figure 9, which also gives Rehbock's two criterions, and shows that this divides his class 2 just about in the middle. To avoid confusion, Rehbock's classification is designated 1, 2, and 3, and the Iowa classification A and B.

If the curve dividing classes A and B in figure 9 were extended beyond $\omega=0.50$, it would have turned upward again and a second value of ω_L would have been indicated for each value of α [6]. Class A flow exists when ω is less than the lower ω_L, and class B flow when ω lies between the two values of ω_L.

[4] Thesis, Leland Stanford University.

[5] The subject is also treated quite fully by Rehbock (*11, 12, 13*). The mathematical treatment given in this bulletin, however, is not an abstract of Rehbock's work but was worked out independently.

[6] In fact there is a third value also, but it is negative. The three roots of the equation are

$$\frac{3\cos\theta}{1-\alpha}-1, \quad \frac{3\sin(\theta-30°)}{1-\alpha}-1 \quad \frac{3\sin(\theta+30°)}{1-\alpha}-1,$$

where θ is defined by the equation: $\cos 3\theta=-(1-\alpha)$. The first expression gives the higher ω_L, the second the lower ω_L, and the third is always negative and without meaning. The values of ω_L for the different channel contractions used in the tests are given in table 4.

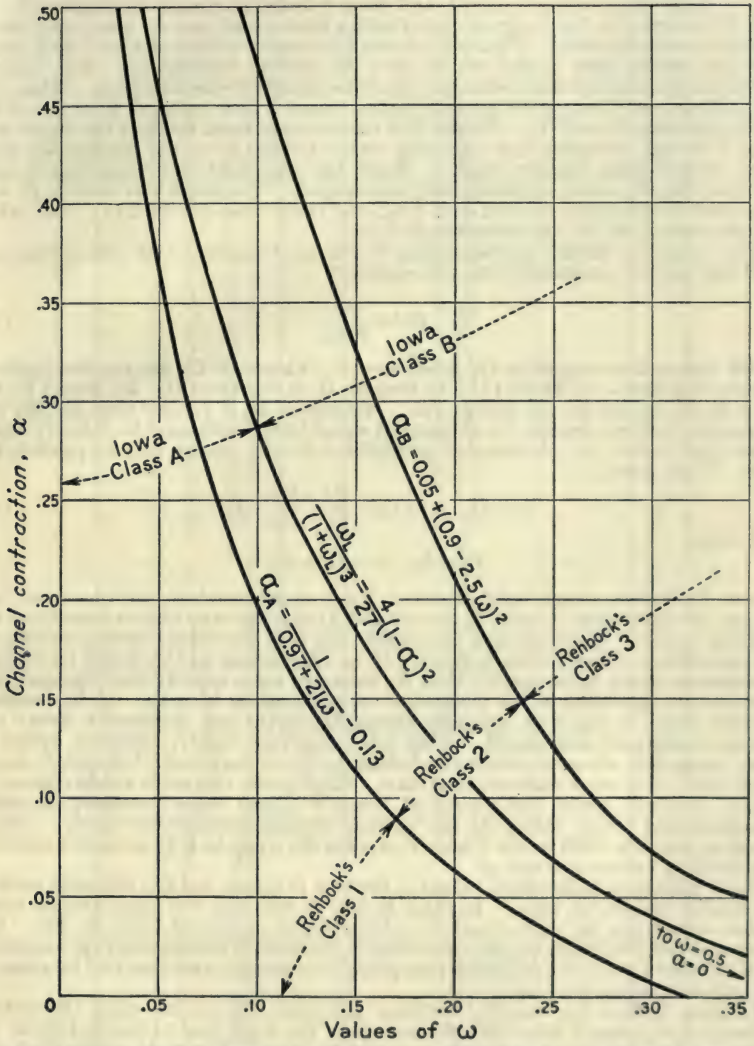
Channel contraction, α
Values of ω
Iowa Class A
Iowa Class B
Rehbock's Class 1
Rehbock's Class 2
Rehbock's Class 3
$\alpha_A = \frac{1}{0.97 + 2\omega} - 0.13$
$\alpha_B = 0.05 + (0.9 - 2.5\omega)^2$
$\frac{\omega_L}{(1+\omega_L)^3} = \frac{4}{27}(1-\alpha)^2$
to ω = 0.5 α = 0

FIGURE 9.—Limits of different classes of flow according to Rehbock's and to Iowa classifications. Note however, that Rehbock's classification is made according to the flow in the unobstructed channel but the Iowa classification relates to the flow through the contracted section.

TABLE 4.—*Limiting values of* ω

α	θ	Cos θ	Sin (θ–30°)	Higher ω_L	Lower ω_L
	° ′				
0.000	60 00	0.5000	0.5000	0.5000	0.5000
.117	50 41	.6336	.3532	1.152	.1994
.233	46 41	.6860	.2871	1.684	.1235
.350	43 31	.7252	.2337	2.347	.0785
.500	40 00	.7660	.1736	3.596	.0419

The distinction between class A and class B is shown clearly by figures 10, 11, and 12, which give the water surface profiles for several runs on piers with semicircular noses and tails. Figure 12 shows the case of a flow of about 68.8 cubic feet per second past a pier which gave 50 percent contraction. The critical depth (in the unobstructed channel) for this quantity was 1.15 feet. When the downstream weir was in its lowest position, class 3 flow resulted with $D_3=0.70$, while upstream $D_1=2.71$. (Eleven feet downstream from the pier the depth was only 0.45 foot, probably due to eddies which formed a virtual contraction even more serious than the pier itself.) When the adjustable weir was raised until D_3 was 1.83, D_1 remained practically unchanged. The same was true as D_3 was increased successively to 2.12 and 2.32, D_1, being now about 2.74. But when D_3 was made 3.08, D_1 was increased to 3.16.

The "limiting depth" corresponding to the ω_L of equation (10) was in this case 2.60 and can be computed from the equation

$$D_L^3=\frac{q_3^2}{2g\omega_L} \tag{11}$$

which comes from equation (9) when $\omega=\omega_L$. Values of D_L are plotted against values of q_3 and α in figure 13. As long as D_3 is less than D_L, D_1, would be the same as D_L except for the energy loss. Whenever D_3 is greater than D_L, D_1 will be correspondingly greater by an amount equal to the difference in velocity heads above and below the obstruction in addition to the energy loss in passing the pier. Then when

$$D_3>D_L,\ D_1=D_3+\frac{V_3^2}{2g}-\frac{V_1^2}{2g}+L_A \tag{12}$$

and when

$$D_3<D_L,\ D_1=D_L+L_B \tag{13}$$

where L_A is the energy head loss and L_B is approximately the pier-nose loss. It may be noted that in both figures 10 and 11 one run was almost exactly at the limiting depth. It should also be pointed out that the actual stream conditions are opposite to those shown in figures 10 to 12, because as the depth increases q increases so much more rapidly that D_L increases more rapidly than D_3, and may overtake it, especially if the proportion of obstruction is large. If D_L becomes greater than D_3 the flow becomes strangulated (to use Rehbock's term) and serious backwater may result. This will occur very rarely, however, except in steep mountain streams where the backwater is unimportant because it would "run out" in a short distance upstream. The whole matter is made clearer by figure 14 which shows the values of Chezy's C and slope necessary to cause "strangulated" flow (class B) for various channel-contraction ratios. Unless the slope exceeds 0.001 or the Chezy C exceeds 90, α can be 0.23 without exceeding the limiting values of ω and q_2.

Koch's method is therefore valuable because it brings out the different sorts of backwater caused by piers. In class B flow it will give the approximate backwater, which can be made exact by adding L_B as explained later (p. 40). But in class A flow, the type usually occurring in practice, it fails entirely, as according to Koch there would be no backwater at all if no energy were lost and he gives no way of computing the loss.

In class A flow the velocity between the piers will be less than the critical velocity. In class B flow the velocity would be, according to Koch, just at the critical value and the water surface would be level. Figure 11 shows that this is approximately true in the case of long piers (length 13 times the width), but figures 10 and 12 show that it is far from true in the case of short piers (length 4 times the width).

EMPIRICAL FORMULAS AND GRAPHIC SOLUTIONS

FORMULA FOR CLASS A FLOW

A study was made of the variation of L_A in equation 12. The first assumption was that as the losses probably varied somewhat as the square of the velocity, they might be taken as varying with $V_3^2/2g$, the velocity head in the natural stream. This was found to be the case in tests where ω was approximately constant, but different values of ω gave different values of L_A for the same value of $V_3^2/2g$. An attempt was therefore made to develop an empirical formula for L_A in terms of $V_3^2/2g$ and ω and a pier-shape coefficient. But since in class A flow the velocity head above the piers is only slightly less than that below, the

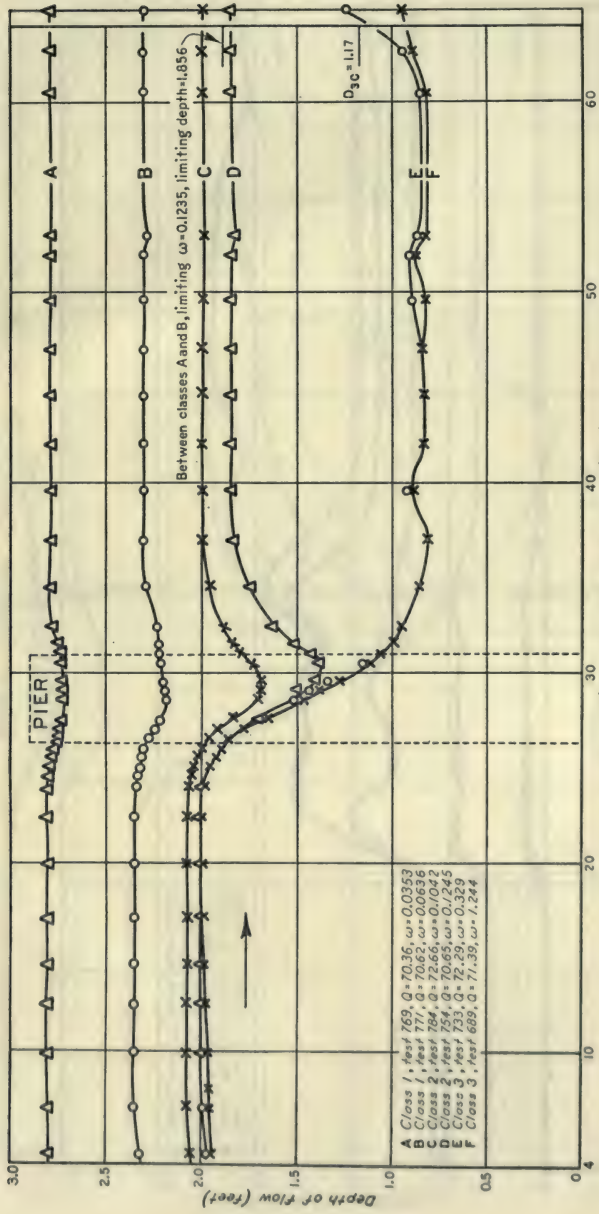

FIGURE 10.—Water surface profiles with twin standard piers having semicircular ends. Channel contraction 23.3 percent, flow 71 cubic feet per second.

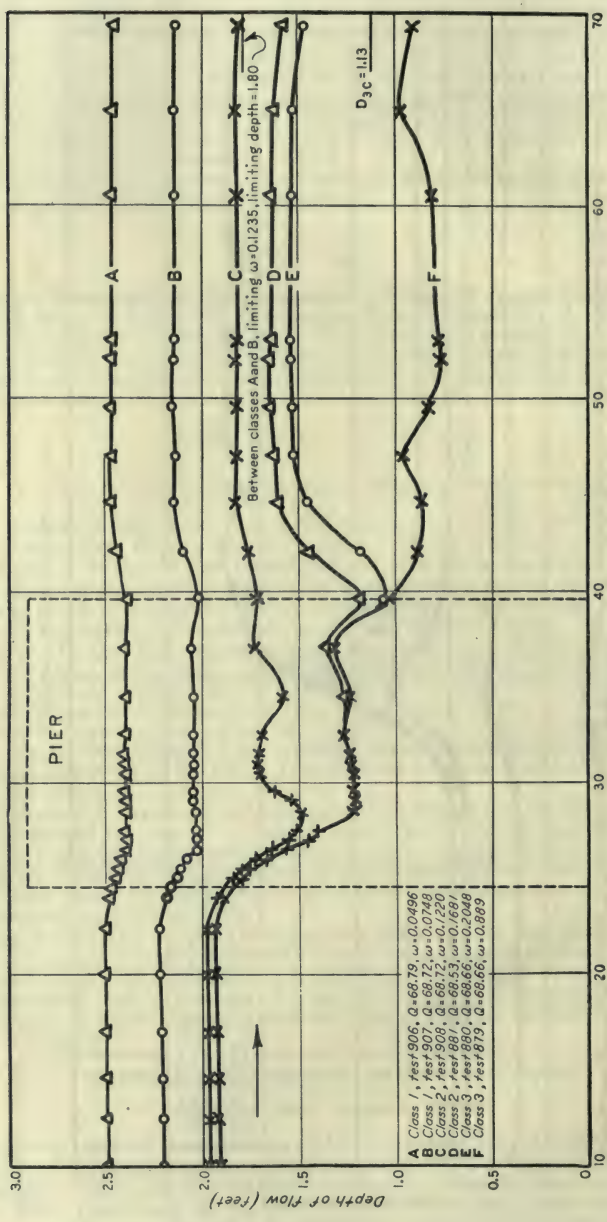

FIGURE 11.—Water surface profiles with twin long piers having semicircular ends. Channel contraction 23.3 percent; flow 68.8 cubic feet per second.

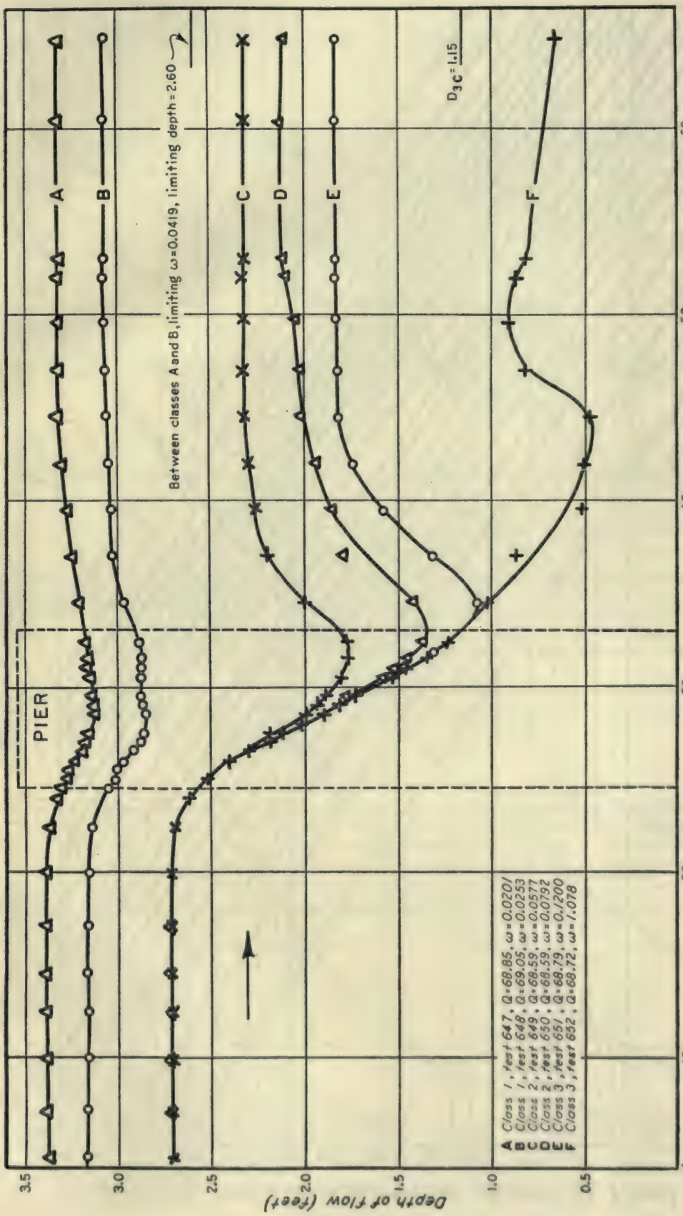
PIER
Between classes A and B, limiting ω=0.0419, limiting depth=2.60
A
B
C
D
E
F
$D_{3/2}=1.15$
Depth of flow (feet)
Distance along testing channel (feet)
A Class 1, test 647, Q=68.85, ω=0.0201
B Class 1, test 648, Q=69.05, ω=0.0253
C Class 2, test 649, Q=68.59, ω=0.0577
D Class 2, test 650, Q=68.59, ω=0.0792
E Class 3, test 651, Q=68.79, ω=0.1200
F Class 3, test 652, Q=68.72, ω=1.078

FIGURE 12.—Water surface profiles with single wide pier having semicircular ends. Channel contraction 50 percent; flow 68.8 cubic feet per second.

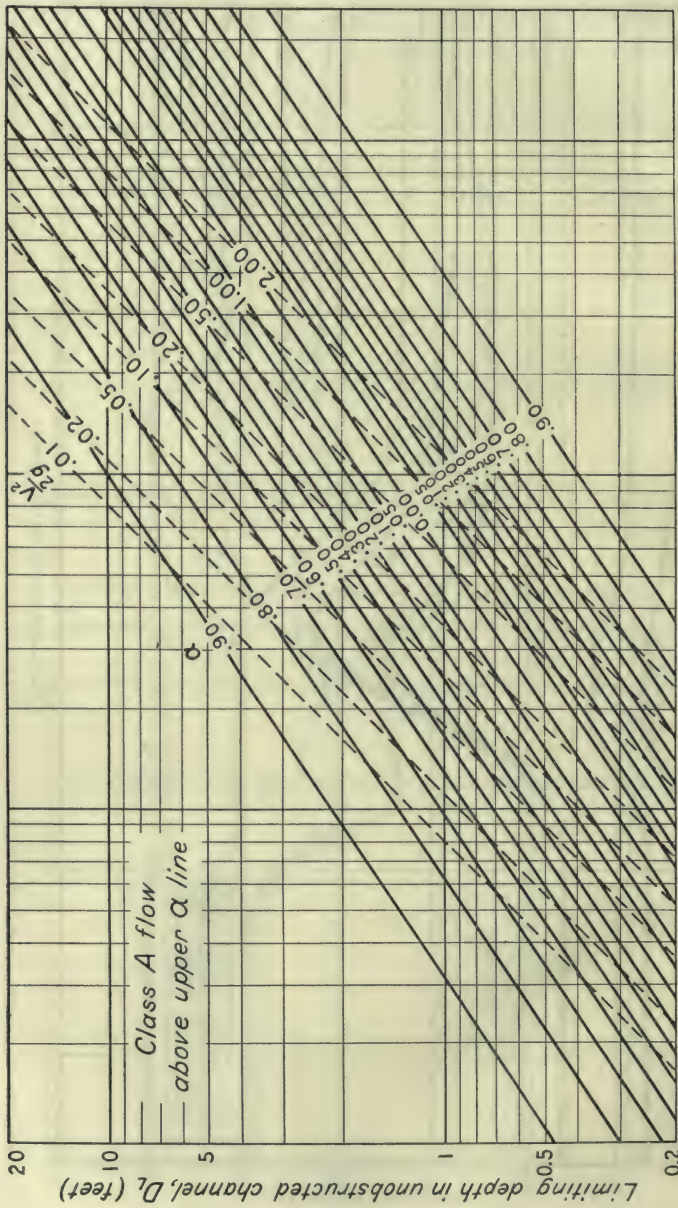

FIGURE 13.—Limiting depth D_L in unobstructed channel for various channel contractions and for various discharges per foot of width in unobstructed channel.

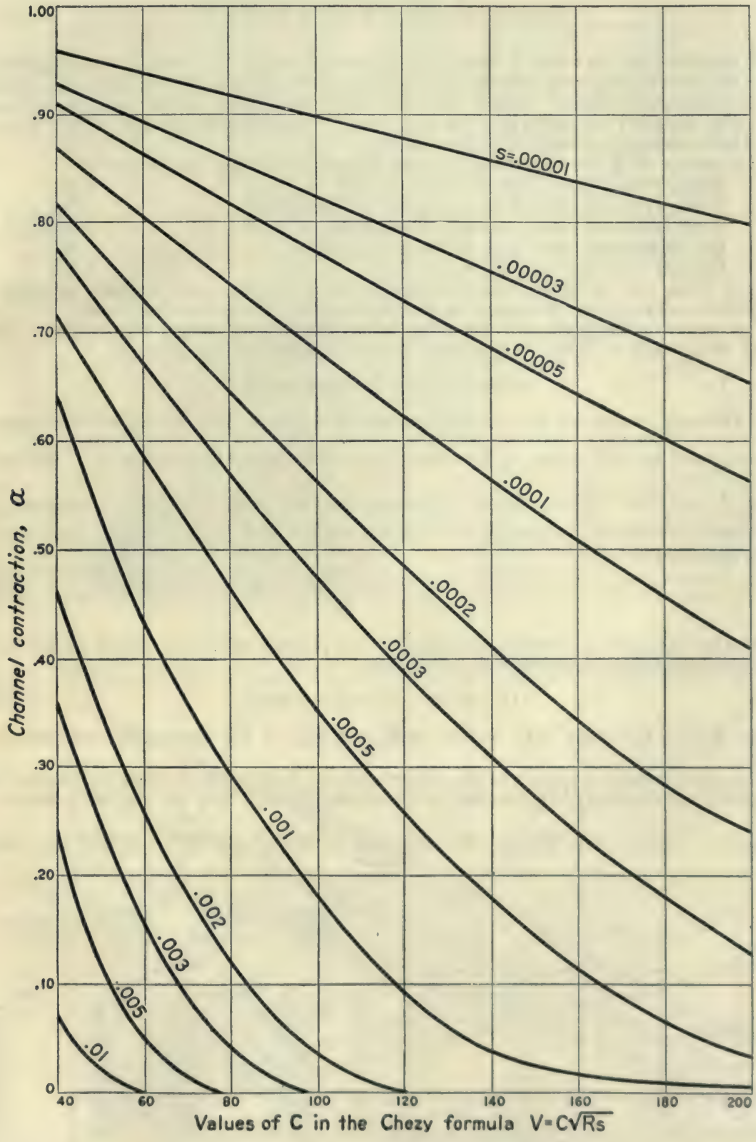

FIGURE 14.—Limiting values of channel contraction, for various values of C and s in the Chezy formula.

surface drop down H_3 is generally only about 10 per cent more than L_A. Therefore the possibility of developing a formula for H_3 directly was investigated and found to be equally satisfactory.

After many trials the following formula was developed:

$$H_3=2K(K+10\omega-0.6)(\alpha+15\alpha^4)\frac{V_3^2}{2g} \qquad (14)$$

This applies only to class A flow, and for some values of α and ω the departure from the curve which represents the average of the data is greater than the probable experimental error. But it lies well within the range of the individual tests and was adopted in preference to any more complicated formula which might have been developed to fit the data better.

The values of K for the principal pier shapes tested are listed below.

Semicircular nose and semicircular tail	0.9
Twin-cylinder piers with connecting diaphragm	.95
Twin-cylinder piers without diaphragm	1.05
90° triangular nose and 90° triangular tail	1.05
Square nose and square tail	1.25

Piers with one or both ends lens-shaped or convex-shaped appear to have a coefficient very nearly the same as that for one with semicircular ends.

The above coefficients are for piers with length four times the width. The effect of increase in ratio of length to width is discussed on page 46.

FORMULAS FOR CLASS B FLOW

In the case of class B flow it was natural to suppose that L_B might be roughly proportional to the square of the velocity of approach; that is, to $\frac{V_1^2}{2g}$. In fact, it was found that when L_B for any given α and pier shape was plotted against $\frac{V_1^2}{2g}$ a straight line could be drawn through the origin and fairly close to the points. That is, we have:

$$L_B=C_B\frac{V_1^2}{2g} \qquad (15)$$

When the values of C_B for each pier shape were plotted against α, it was found that they could be represented by the equation

$$C_B=0.50+K_B(5.5\alpha^3+.08) \qquad (16)$$

where $K_B=5$ for piers with square ends and $K_B=1$ for piers with semicircular ends.

The arithmetical average of the discrepancies between the observed values of H_3 and those computed by the use of formulas (15) and (16) are shown in table 5.

TABLE 5.—*Differences between observed and computed backwater heights for class B flow*

Shape of pier	Channel-contraction ratio	Tests averaged	Average observed H_3	Average difference
		Number	*Feet*	*Feet*
Square ends	0.1167	2	0.18	0.023
	.2333	84	.64	.030
	.350	41	.57	.011
	.500	51	.79	.011
Semicircular ends	.1167	1	.13	.026
	.2333	70	.722	.024
	.3500	45	.495	.012
	.5000	48	.6	.010
Lens-shaped ends	.2333	45	.672	.021

DEVELOPMENT OF GRAPHS

A series of curves has been prepared to facilitate the computation of backwater for actual cases. Figure 13 gives the D_L for any given q and α. If D_3 is more than D_L, the flow is class A; if less, it is class B.

For class A flow, turn to the upper part of figure 15 and from the appropriate values of α and V_3 read the value of $x=\frac{V_3^2}{2g}\alpha(1+15\alpha^3)$. Then enter the lower

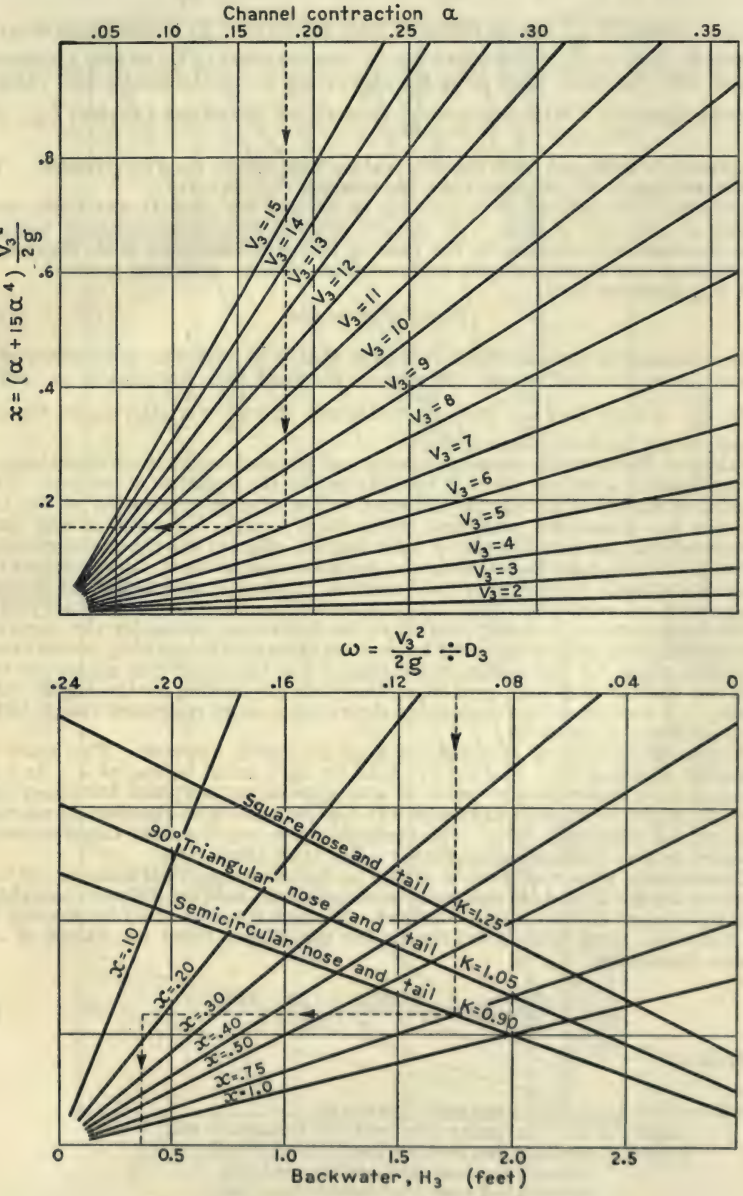

FIGURE 15.—Chart for determining backwater in class A

part with this value and the proper values of ω and K, and read the backwater, H_3. If the backwater is given and it is required to find the discharge, it will be

necessary to assume a value of V_3 and work by trial error until the solution is found.

For class B flow, turn to figure 16 and go up from the given α to the curve representing the given pier shape, then horizontally to $\frac{V_1^2}{2g}$ and then vertically to L_B. Values of $\frac{V_1^2}{2g}$ can be obtained from figure 13. As a first approximation assume D_1 equal to D_L. Then add the L_B thus obtained to D_L to give a corrected D_1 and with this value (and using the same scale as for D_L) read a new value of $\frac{V_1^2}{2g}$ from figure 13. With this new $\frac{V_1^2}{2g}$ enter figure 16 and get a revised L_B. If it s appreciably different from the first value, the process may be repeated. The backwater height H_3, is given from the relation $H_3=D_1-D_3$.

Although this method of computing backwater for class B was fairly satisfactory in the case of piers with square, semicircular, or lens-shaped noses, it gave unsatisfactory results in the case of twin-cylinder piers with diaphragm. An attempt was therefore made to develop an entirely empirical method.

It was assumed that

$$H_3=KD_3 f_1(\alpha)f_2(\omega) \tag{17}$$

From dimensional considerations it is clear that if H_3 varies as some power of D_3 it must be as the first power. Of course, H_3 could have been taken as varying with $\frac{V_3^2}{2g}$ or with $D_3+\frac{V_3^2}{2g}$, but $\frac{V_3^2}{2g}=\omega D_3$ and $D_3+\frac{V_3^2}{2g}=\frac{V_3^2}{2g}(1+\omega)$, so the only change would be in the form of $f_2(\omega)$.

Values of H_3/D_3 for the same pier shape and channel contraction were therefore plotted against ω and an attempt made to derive the equation of the line. Then by finding similar equations for different values of α determination of the form of $f_1(\alpha)$ was attempted, and then of the form $f_2(\omega)$. However, it was finally discovered that the simplest way of including the effect of the channel contraction was to plot H_3/D_3 against ω/ω_L where ω_L is the lower limiting ω. It was found that this automatically took care of the variation in channel contraction as is shown in figure 17, where all the values for the pier with square nose and square tail fall on the same curve. To avoid confusion, the individual points for the piers with semicircular nose and semicircular tail are not shown although they plotted about as well as those for the square-ended piers. For the other pier shapes no tests were run with $\alpha=0.35$ and $\alpha=0.50$, so that data are lacking for the higher values of ω/ω_L. A number of the shapes are shown for a more restricted range, but at at larger scale, in figure 18.

Certain limitations of this method must be noted, however. The limits are indicated on figure 17. Nor does it hold for very small values of α. As α approaches zero, the maximum value of ω/ω_L approaches one; and the upper limit of H_3/D_3 might be as great as from 0.9 to 1.5, depending on the pier shape, when it should be practically zero. The methods given below should therefore not be expected to give reasonable results for α less than about 0.05.

Considerable time was spent in trying to derive an empirical formula for these curves in figures 17 and 18, especially one that would hold for different pier shapes with the change of but a single constant. No such formula could be derived, but the following gives fairly good results for the shapes listed for values of ω/ω_L greater than unity:

$$\frac{H_3}{D_3}=Kx^{0.4}+\frac{(0.045x^2+1.1x-0.98)x}{x^2+3.3x+1}, \tag{18}$$

wherein $x=\frac{\omega}{\omega_L}$

and $K=0.136$ for square nose and square tail,
0.096 for 90°-triangular nose and 90°-triangular tail,
0.070 for semicircular nose and semicircular tail,
lens-shaped nose and lens-shaped tail,
lens-shaped nose and semicircular tail,
and convex nose and convex tail.

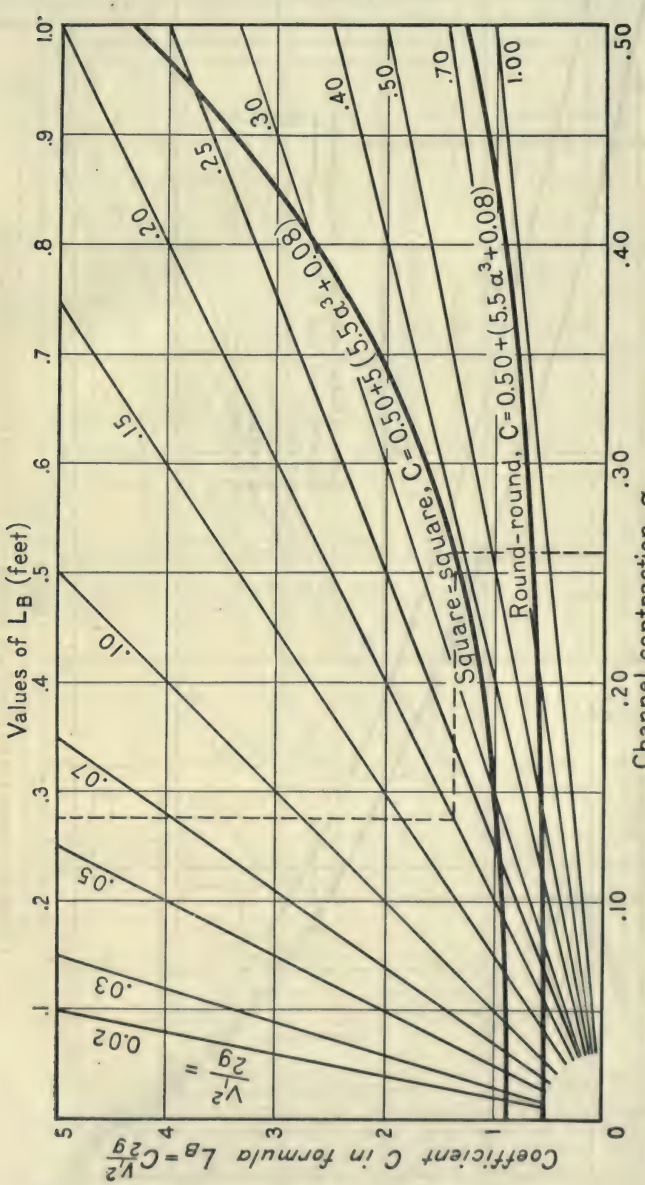

FIGURE 16.—Chart for determining L_B in class B flow.

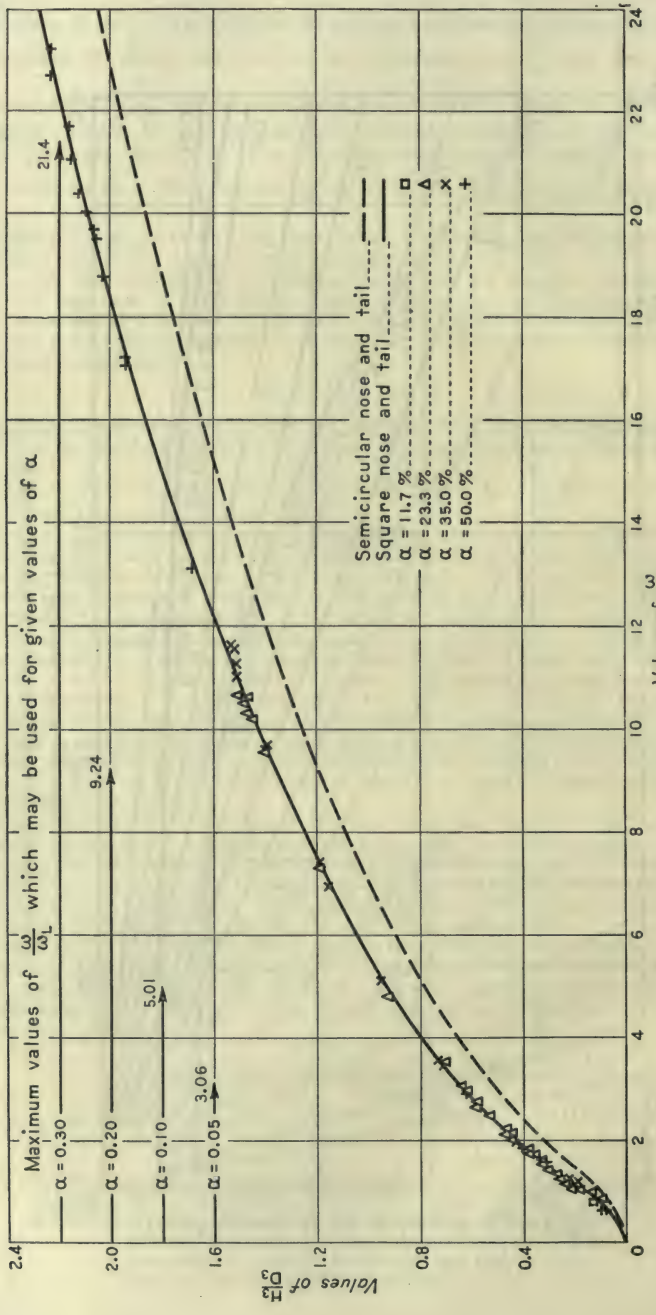

FIGURE 17.—Variation of H_3/D_3 with ω/ω_L for piers with square and semicircular noses and tails.

However, it generally will be simpler to use the curve itself rather than this formula. Find ω from equation (9) and ω_L from equation (10), table 4, figure 9; then with ω/ω_L enter figure 18 or figure 17 and read H_3/D_3 for the given pier shape. This multiplied by D_3 gives H_3, the backwater height. Or, if D_1, D_3, W_2, W_3, and the pier shape are known and it is required to find the discharge, H_3/D_3 may be calculated from $H_3/D_3=(D_1-D_3)/D_3$, ω/ω_L be taken from figure 18 or figure 17,

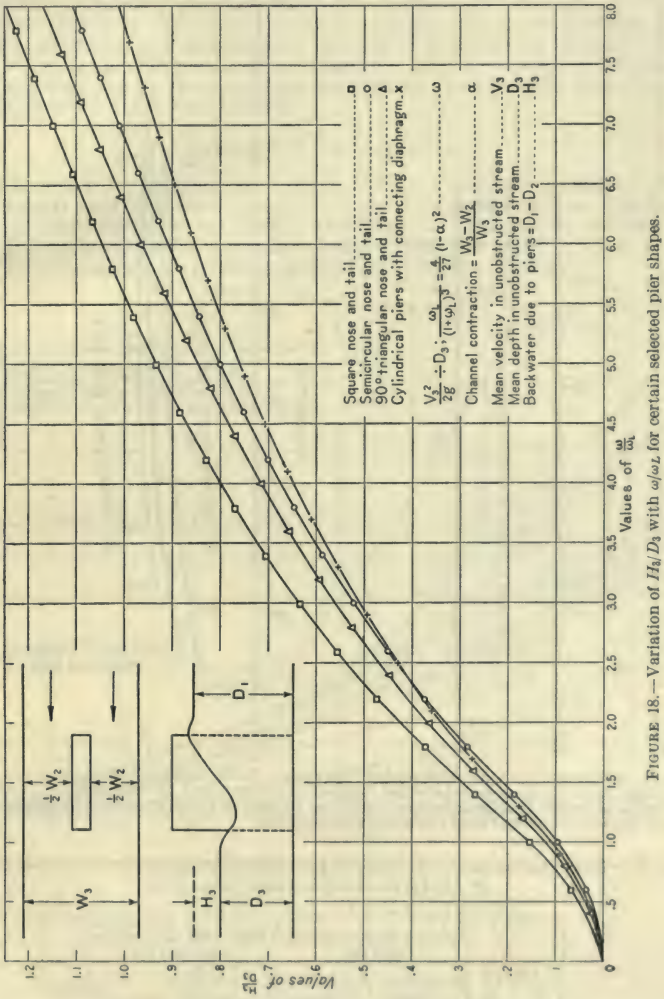

FIGURE 18.—Variation of H_3/D_3 with ω/ω_L for certain selected pier shapes.

$\alpha=(W_3-W_2)/W_3$, and ω_L obtained from figure 9 or equation (10). The value of ω can then be computed, and from it Q by the equations $q_3^2=2g\omega D_3^3$ and $Q=q_3W_3$.

Figure 19 is an alignment chart which may be substituted for this method for piers with square, triangular, or semicircular ends if ω/ω_L does not exceed 1.8. Difficulty was encountered in trying to develop a single alignment chart that would hold throughout the entire range of the experiments and all classes of flow.

EFFECT OF INCREASE IN LENGTH OF PIERS

Curves were also drawn of H_3/D_3 against ω/ω_L for the piers where the ratios of length to width were 7 and 13 instead of 4. Comparison of these curves with those in figures 17 and 18 for piers with square and with semicircular ends is shown in table 6.

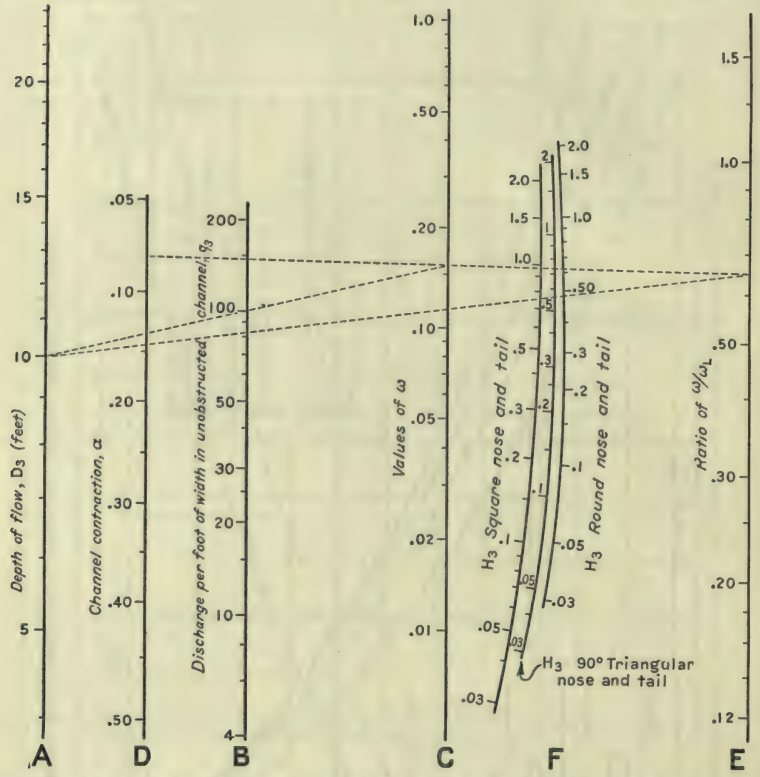

FIGURE 19.—Alignment chart for determining backwater. From depth and discharge (scales A and B) determine ω (scale C); from ω and channel contraction (scales C and D) determine ω/ω_L (scale E; from depth and ω/ω_L (scales A and E) determine backwater H_3 (scale F for appropriate pier shape). Reasonable accuracy cannot be expected from extensions of these scales.

TABLE 6.—*Ratios of values of H_3/D_3 for pier length-width ratios of 7 and 13 to value of H_3/D_3 for length-width ratio of 4*

ω/ω_L	Piers with square nose and tail		Piers with semicircular nose and tail	
	$L/W=7$	$L/W=13$	$L/W=7$	$L/W=13$
0.5	0.82	0.96	0.83	0.89
1.1	.90	.97	.93	1.00
2.0	.97	1.00	1.00	1.09
3.0	.97	.98	1.04	1.08
7.0	.98	1.00	1.02	1.04

As only these three values of L/W were investigated, it is uncertain whether 7 is the optimum length-width ratio for a pier with square nose and tail. It seems probable that the optimum ratio is different for different values of ω/ω_L. In the case of the semicircular nose and tail the optimum is apparently less than 7, being definitely so for ω/ω_L greater than 2.

Apparently there are two opposing effects. Increasing the length of the piers must increase the friction loss but up to a certain length it decreases the eddy loss, and the latter is greater, especially with the square nose and tail. It has been pointed out elsewhere (*18*) that an abrupt entrance tends to decrease friction losses for a short distance downstream because of its effect on velocity distribution, the velocity along the walls being reduced. This is probably one reason why the backwater caused by the long piers was greater when the pier ends were semicircular than when they were square.

COMPARISON OF FORMULAS

Figure 20 gives the curve obtained from the Iowa tests for piers with semicircular noses and tails (the same as in figs. 17 and 18), and the curves which would be given by the D'Aubuisson, Nagler, and Rehbock formulas for several values of α using the average coefficients for classes 1 and 2 as given in table 1.

These three formulas may be changed into the following forms:

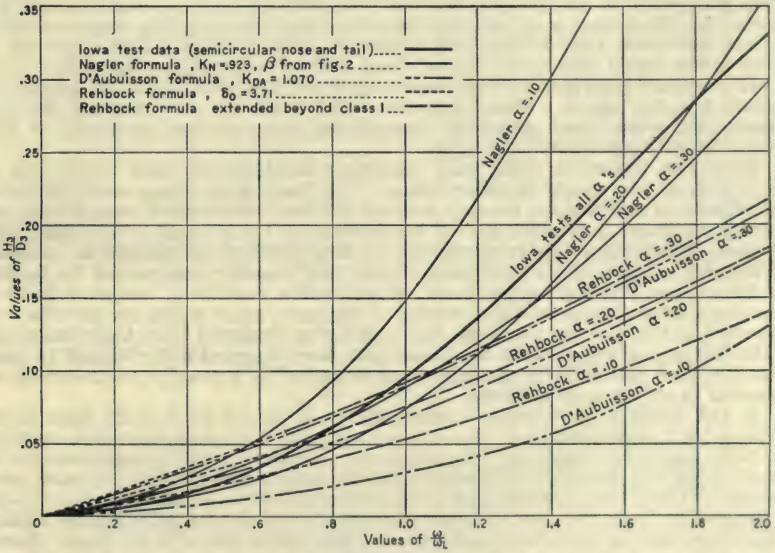

FIGURE 20.—Comparison of bridge pier formulas with results of Iowa tests on basis of ratio of H_3/D_3 to ω/ω_L

$$\text{D'Aubuisson:}\quad \frac{H_3}{D_3}=\left[\frac{4}{27K^2_{D'A}}\frac{(1+\omega_L)^3}{\omega_L}-\left(\frac{D_3}{D_1}\right)^2\right]\omega$$

$$\text{Nagler:}\quad \frac{H_3}{D_3}=\left[\frac{4}{27K_N^2\omega_L(1-.3\omega)^2}-\beta\left(\frac{D_3}{D_1}\right)^2\right]\omega$$

$$\text{Rehbock:}\quad \frac{H_3}{D_3}=[\delta_o-\alpha(\delta_o-1)][0.4\alpha+\alpha^2+9\alpha^4]\omega(1+2\omega)$$

If the best coefficient for each channel contraction had been used, all of the curves would have fitted fairly well up to about the limit of class 1, or about $\omega/\omega_L=0.7$. (Rehbock's formula is not supposed to fit beyond this.) For higher values of ω the D'Aubuisson formula departs from the test curve far beyond the range of experimental error, unless the coefficient is made to vary with ω as well as with the pier shape. The Nagler formula fits fairly well to a higher limit. If the coefficients in each of the formulas are kept constant for each pier shape, as appears

to be intended by their authors, the results depart widely from these tests for most values of α, as is shown by figure 20.

All the tests were made in channels with rectangular cross section. How satisfactorily these formulas can be applied to actual river channels, by estimating equivalent rectangular cross sections, is not yet determined.

It is believed that these formulas will apply to larger piers without error due to the scale of the model, because the formulas are dimensionally homogeneous (except for $\sqrt{2g}$, which is constant) and because they check with Nagler's Michigan tests which were on smaller models.

VELOCITY DISTRIBUTION AROUND PIERS

In connection with the experiments on the obstruction of bridge piers to flow of water, two sets of tests were made in which the velocity distribution around the pier was determined. With a flow of 24.1 cubic feet per second, velocities passing a pier with square nose and square tail were measured at various points in 11 cross sections in the channel, and the water-surface contours around this pier were determined for two depths of flow.

To locate the position of the point at which each velocity reading was taken, it was necessary to build a device by means of which the coordinates of each point of observation could be determined. A 4-inch angle iron 12 feet long was secured horizontally to each wall of the canal at the site of the pier. Telemeter rods graduated to hundredths of a foot were bolted to these angle irons. Supported by these bars and spanning the canal was a main guide frame consisting of two telemeter rods 10 feet long placed on 3-inch T-bars 3 feet apart (pl. 8). This guide frame was easily moved back and forth along the side rods. On it were two short cross frames, each consisting of two telemeter rods 3 feet long spaced about 3 inches apart. Metal supports which could be moved along the cross frame held either hook gages for determining water surface elevations or Pitot tubes for making velocity traverses.

Thus two observers could take readings simultaneously and obtain the coordinates of the points of observation. The hook gage frame could be moved lengthwise of the channel through a range of 3 feet on the small cross-frames, and each cross frame was easily moved transversely of the channel on the main guide frame. The main guide frame was moved lengthwise of the channel as necessary. With each reading of his hook-gage vernier, the observer determined the location of his gage on the short cross frame, as well as the position of this cross frame on the main guide frame and the setting of the main guide frame on the side rods. For taking the velocity readings, the hooks were removed from their frames and Pitot tubes made especially for these tests were inserted and clamped in place. The pressure and velocity columns were mounted on a wooden frame which was secured to the hook-gage frame.

In the velocity distribution studies shown in figures 21 and 22, each section represents a cross section of the channel showing the actual measured velocities in their respective locations. In addition to measuring the velocities at the site of the pier, the direction of flow at various points in the channel was also determined. The studies showed that the direction of flow near the pier nose is to some extent away from the pier, whereas the direction of flow at points some distance from the pier is directly downstream. The Pitot tubes were faced directly upstream, so the measurements recorded and platted are only the longitudinal components where flow was oblique to the axis of the canal. Figure 21 shows velocities next to the pier appreciably greater than velocities some distance away, along the upper portion of the pier. Figure 22 shows a generally similar velocity distribution, with a greater depth but the same quantity of flow and therefore lower velocity. Critical velocity existed at certain sections in figure 22, particularly at stations 4.75, 5.75, and 6.75. This condition, which caused the unusually high velocities around the pier nose, would seldom be met with in actual practice.

Elevations of the water surface were taken at various points in the channel. These elevations were plotted in their respective locations as shown in figures 23 and 24, in which contours make the drop down of the water surface around the pier nose readily apparent.

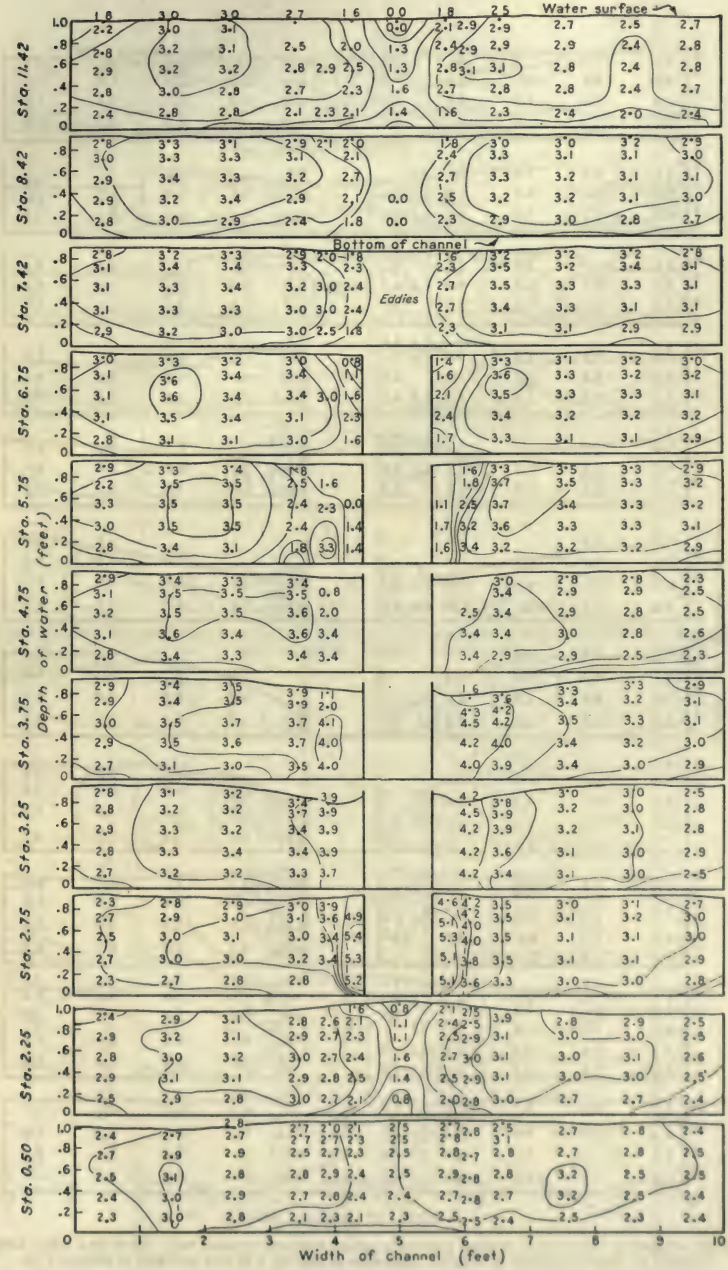

FIGURE 21.—Velocity distribution around pier with square nose and square tail. Flow 24.1 cubic feet per second; D_3 approximately 1.0 foot. Pier nose at station 2.63 and pier tail at station 7.30.

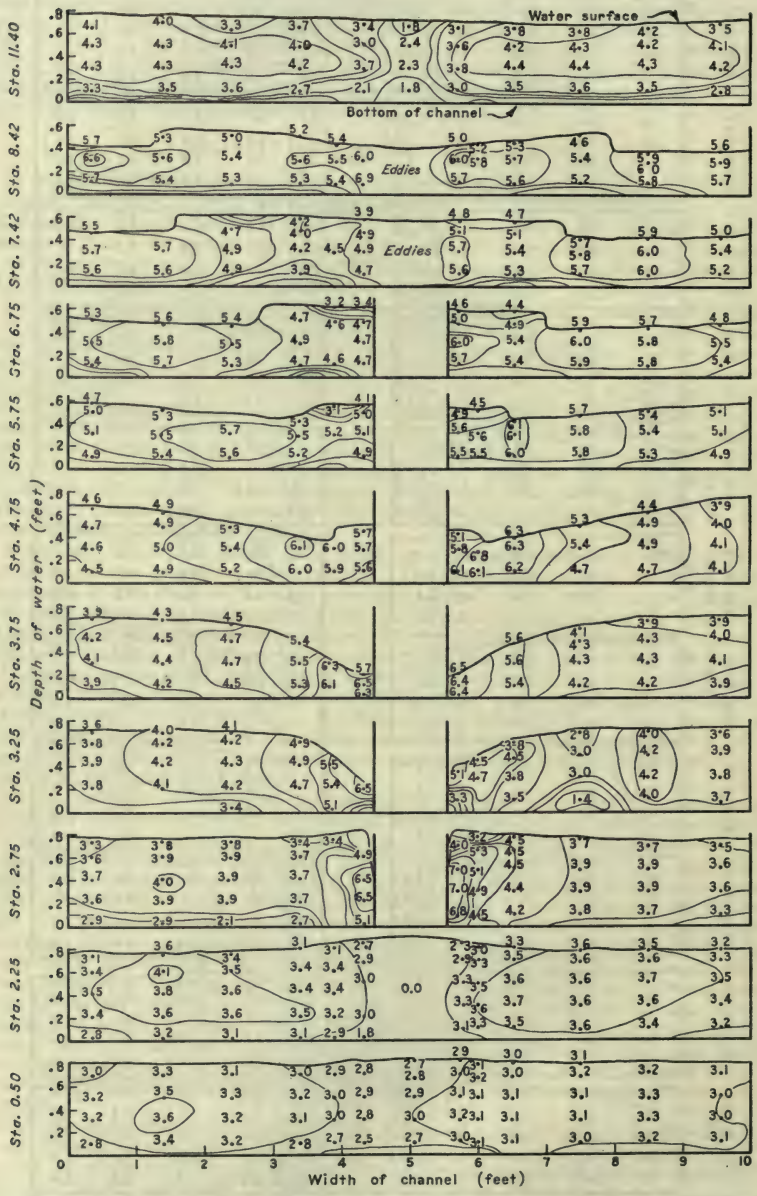

FIGURE 22.—Velocity distribution around pier with square nose and square tail. Flow 24.1 cubic feet per second; D_3 approximately 0.75 foot. Pier nose at station 2.63 and pier tail at station 7.30.

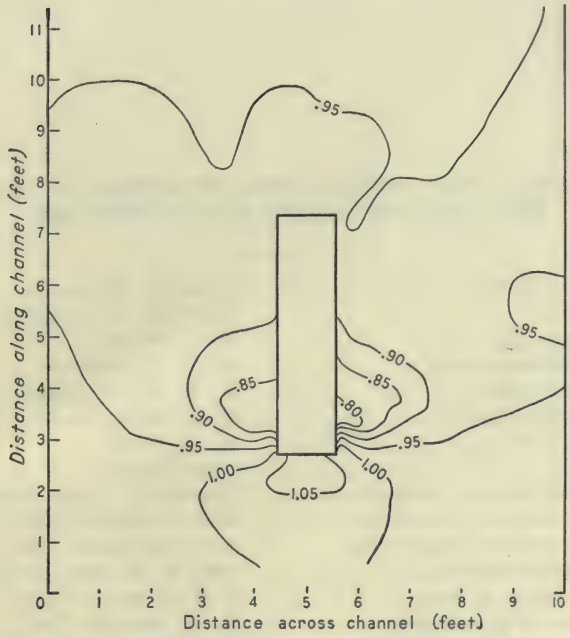

FIGURE 23.—Water surface contours (in feet) about square-ended pier with flow of 24.1 cubic feet per second and D_3 about 1.0 foot. (See fig. 24.)

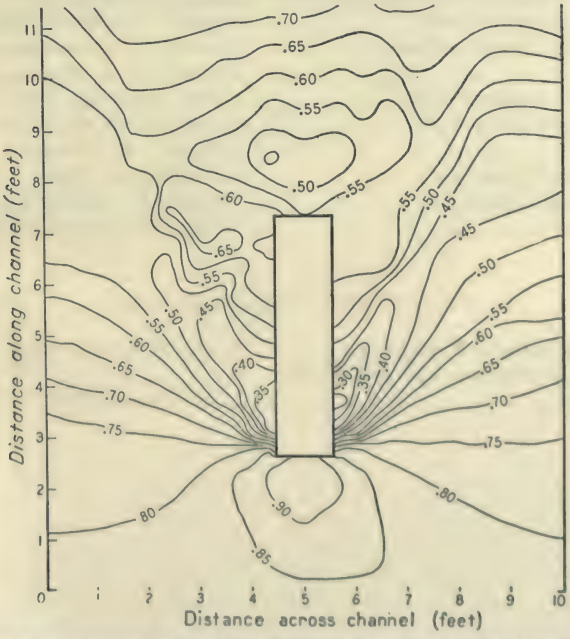

FIGURE 24.—Water surface contours (in feet) about square-ended pier with flow of 24.1 cubic feet per second and D_3 about 0.75 foot. (See fig. 23.)

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THE BIOLOGY OF CREMASTUS FLAVOORBITALIS (CAMERON), AN ICHNEUMONID PARASITE OF THE EUROPEAN CORN BORER

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INTRODUCTION

Cremastus flavoorbitalis (Cameron) is a larval parasite of the European corn borer (*Pyrausta nubilalis* Hbn.) in the Orient. It was first introduced into the United States in the winter of 1928–29 and was liberated during the summer of 1929 to aid in the biological control of the corn borer in this country. Recently imported stock has also been received at the Bureau of Entomology laboratory at Moorestown, N.J., and liberated in Pennsylvania as a parasite of the oriental fruit moth (*Grapholitha molesta* Busck).

C. flavoorbitalis is an ichneumonid parasite belonging to the subfamily Ophioninae. It was first described as *Tarytia flavo-orbitalis* by Cameron (*1*)[2] in 1907. In a recent paper by Cushman (*2*) it is shown that *flavoorbitalis* is the correct designation for this species and that the name *C. hymeniae*, first used by Viereck (*12*) and later by a number of other writers, is a synonym.

[1] The writers gratefully acknowledge their indebtedness to D. W. Jones, S. M. Dohanian, and A. M. Vance for their criticisms and helpful suggestions during the preparation of this bulletin, and to B. E. Hodgson and J. G. Pratt for the photographs.

[2] Italic numbers in parentheses refer to Literature Cited, p. 15.

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The main purpose of this bulletin is to present descriptions of the immature stages of this insect, the results of studies of its biology, and information concerning the status of the species as a parasite of the European corn borer.

HOST RELATIONSHIPS

Under the name *Cremastus hymeniae*, *C. flavoorbitalis* is recorded by Viereck (*12*) as successfully reared from *Hymenia fascialis* Cram., the Hawaiian beet webworm, by H. O. Marsh in Honolulu.

Morley (*3, p. 506*) states that this insect is parasitic in India on *Euzophera perticella* Rag., *Antigastra catalaunalis* Dup., *Eucosma paragramma* Meyr., and *Chilo simplex* Butl.

The greatest number of hosts recorded for this parasite was compiled by Swezey (*6*; *7, p. 13; 9*) in Hawaii. They are given below.

Phycitidae: *Genophantis iodora* Meyr. and *G. leahi* Sw.
Pyraustidae: *Omiodes blackburni* (Butl.), *O. accepta* (Butl.), *O. meyricki* Swezey, *O. monogona* Meyr., *O. musicola* Swezey, *O. locali*s (Butl.), *Hymenia recurvalis* (Fab.), *Phlyctaenia stellata* (Butl.), *P. calcophanes* Meyr., *P. platyleuca* Meyr., *P. iocrossa* Meyr., *Phlyctaenia* sp., and *Chilo simplex* (Butl.).
Tortricidae: *Tortrix metallurgica* Walsm., *Epagoge infaustana* Walsm., *Capua santalata* Swezey, and *C. reynoldsiana* Swezey.
Eucosmidae: *Adenoneura falsifalcellum* Walsm., *Argyroploce illepida* (Butl.), *Crocidosema marcidellum* (Walsm.), *C. lantana* Busck, and *Bactra straminea* (Butl.).
Carposinidae: *Heterocrossa graminicolor* Walsm.
Cosmopterygidae: *Batrachedra cuniculator* Busck and *Pyroderces rileyi* (Walsm.).
Tineidae: *Ereunetis minuscula* Walsm. and *E. flavistriata* Walsm.
Cygnodidae: *Petrochroa dimorpha* Busck.

Swezey (*8*) reports this insect as valuable in the control of the sugarcane leaf roller, *Omiodes accepta*, and the coconut leaf roller, *O. blackburni*.

Cushman (*2*) records that the national collection includes specimens of *C. flavoorbitalis* from Japan reared from *Pyrausta nubilalis* Hbn. and *Grapholitha molesta* Busck; from Hawaii from *Hymenia fascialis* Cramer and *H. recurvalis* Fab.; and from the Philippine Islands from *Crocidolomia binotalis* Zell.

The junior writer has bred this species under laboratory conditions from *Pyrausta nubilalis*, the European corn borer.

DESCRIPTIONS

ADULT

Cameron (*1, p. 589*) described the female of *Cremastus flavoorbitalis* in 1907 as *Tarytia flavo-orbitalis*. Morley (*3*) described both male and female of the species in 1913.

The following is a brief description of the adult, designed to distinguish it from other parasites of the European corn borer:

It has a slender, testaceous body with broad and rather abbreviated wings. The face is distinctly punctate, with the epistoma elevated and the clypeus distinctly discrete and apically margined.

Photographs of the adults are shown in plate 1, *A* and *B*.

EGG

The egg of *Cremastus flavoorbitalis* is elongate-ovoid or kidney-shaped, with both ends bluntly rounded. The chorion is smooth,

bearing no spines or external processes. It is pearly white. The average length is 0.513 mm, and the average width through the center of the egg is 0.167 mm (fig. 1). At the time of hatching the mature embryo is folded, jackknife fashion, within the chorion of the egg, i.e., the head and tail are bent forward on the remainder of the body within the shell.

The duration of the egg stage is 84 hours or 3½ days. (All statements concerning the duration of the various stages of this insect are based on observations made at a constant temperature of 80° F. and a constant relative humidity of 70 percent.)

LARVA

Three instars of the larva of *Cremastus flavoorbitalis* have been observed by the writers. Their descriptions follow.

FIRST INSTAR

The primary larva of *C. flavoorbitalis* is of the caudate or tailed type. It has a heavily sclerotized, testaceous head. The body is divided into 13 segments. The last abdominal segment is developed into a long, narrow, tapering tail. The body is creamy white and has no spines or hairs. The first instar lasts 5 days. During this period the body changes markedly in appearance and in size. The head, however, remains the same throughout these changes.

FIGURE 1.—Egg of *Cremastus flavoorbitalis*, ×50.

One day after hatching the larva has an average length, including the tail, of 1.3 mm and an average width at the widest part of the body of 0.15 mm. The length of the tail is approximately half the entire length of the body and presents a ruffled or uneven appearance. Each of the 12 remaining body segments has a double row of "scallops" running around the body in the middle of each segment (fig. 2, *A*). Apparently this structure permits the body to expand more readily.

The 2-day-old larva (fig. 2, *B*) measures 2.5 mm in length and 0.19 mm in width. The tail is still approximately half the entire length of the body. The remaining body segments are nearly smooth, having only vestiges of their ruffles.

At the time of molting into the second instar, 5 days after the hatching of the egg, the larva (fig. 2, *C*) averages 3.6 mm in length and 0.31 mm in diameter. The tail is now about one-third the entire length of the body. The body segments have become expanded to their maximum size, leaving no trace whatsoever of the scalloped appearance that was in evidence earlier.

In the first instar the larval head is testaceous, heavily sclerotized, somewhat thimble-shaped, and has on the dorsal surface two grooves originating at the posterior boundary of the head and running anteriorly about three-fourths of its length. A slight ridge on each side of the head extends posteriorly from the insertion of the mandibles. On the dorsal portion of the head between the grooves there are no spines or sensory hairs (fig. 3). Laterally (fig. 4) there are seven pairs of small spines on the head: One spine (*a*) at the anterior end of the head about one-half the distance between the mouth parts and the end of the dorsal groove; one spine (*c*)

slightly ventrad and slightly caudad of the anterior end of the dorsal groove; a group of three spines (*b*, *d*, *f*), which might be connected by a curve, midway between the mandible and the dorsal

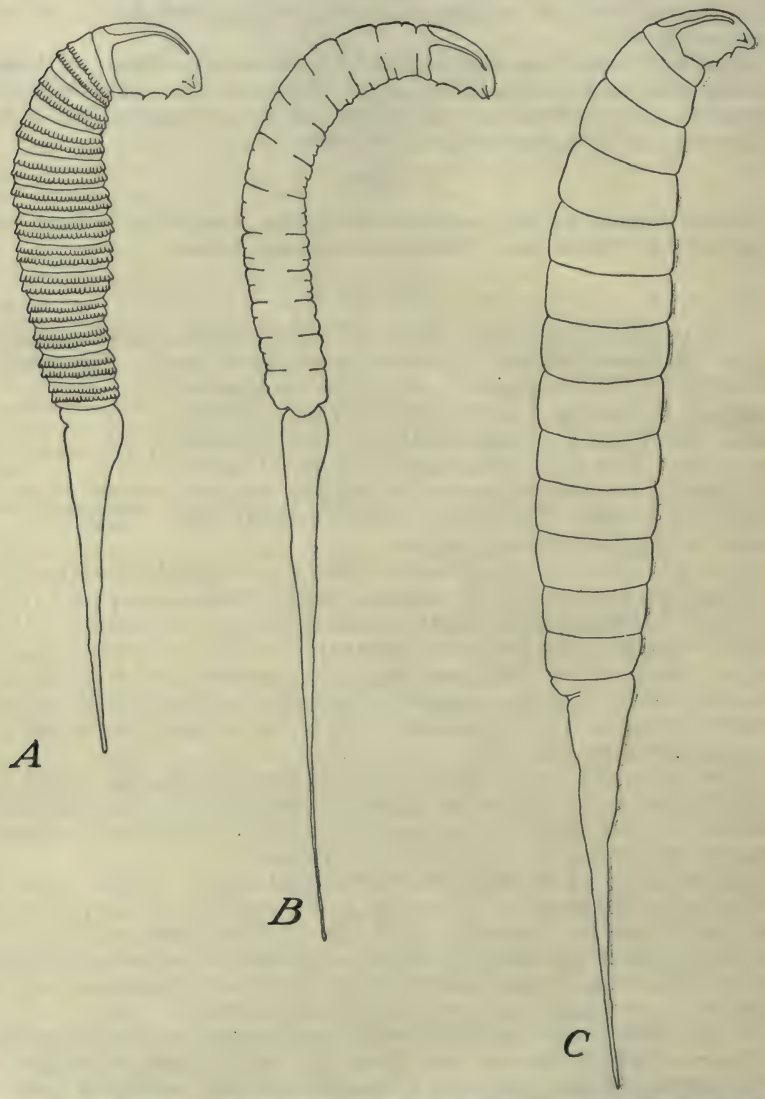


FIGURE 2.—First-instar larva of *Cremastus flavoorbitalis: A*, Larva 96 hours after oviposition, showing annular rings, ×75; *B*, larva 144 hours after oviposition, ×45; *C*, larva 240 hours after oviposition, ×30.

groove; one spine (*h*) in a caudad-central position near the lateral ridge; and one spine (*k*) in a central-posterior position. The ventral surface (fig. 5) supports three pairs of small spines and one pair of large spines. One pair of spines (*e*) is situated on the

anterior portion caudad of the mouth parts and is separated by about the width of two mandibles. Another pair (*g*) is midway on the head and is separated by the width of one mandible. The third pair (*i*) is on the posterior part of the head and is separated by a distance twice as great as that between the preceding pair. The large spines (*j*) are situated immediately caudad of the third pair of small spines and are separated by the same distance. These large spines are set on tubercles.

First-instar larvae of *C. flavoorbitalis* possess distinctly defined mouth parts. The entire mouth-part structure is circular in shape (fig. 6, *A*). The labral region is semicircular and has within its borders several areas that are but thinly sclerotized. One large area within the labral region is located in a dorsal position. Laterad and slightly ventrad of this are two smaller areas within the labral structure. Supplmentary to these are eight minute similarly constructed areas. There are no spines or hairs. In the oral cavity there are two large spines. The maxillary and labial region consists of two pairs of triangular structures, their apices directed toward the center of the oral cavity. The mandibles are simple, strongly curved, and rather sharply pointed. The mandibular condyle is well developed (fig. 6, *B*).

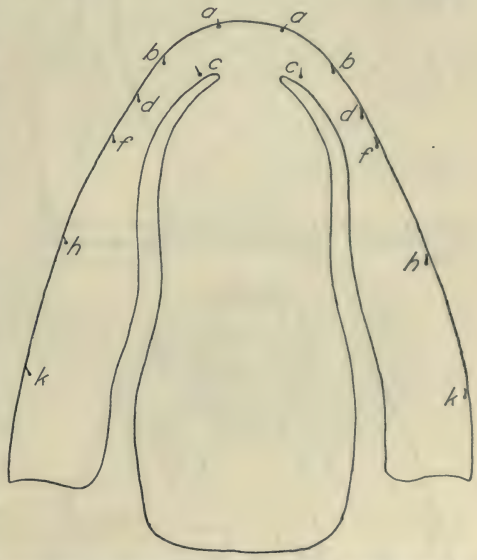


FIGURE 3.—Dorsal view of head of first-instar larva of *Cremastus flavoorbitalis*, showing placement of spines.

SECOND INSTAR

The larval period of the second instar lasts but 1 day. The parasite, however, is markedly different in appearance from what it was during the first instar. It measures on the average 3.8 mm in length and 0.7 mm in width. The head has become rounded and is very thinly sclerotized. The tail has been reduced to a very short robust process (fig. 7, *A*). The mandibles are very lightly sclerotized and are less strongly curved; they are nearly triangular and stout (fig. 7, *B*).

THIRD INSTAR

The mature or third-instar larva of *Cremastus flavoorbitalis* measures 8.2 mm in length and 2.05 mm in width and is dirty white. The body consists of 13 segments. The spiracles are situated on the first thoracic and the first eight abdominal segments. The wing buds are visible on the mesothoracic and metathoracic segments, and the leg buds are visible through the wall of the three thoracic seg-

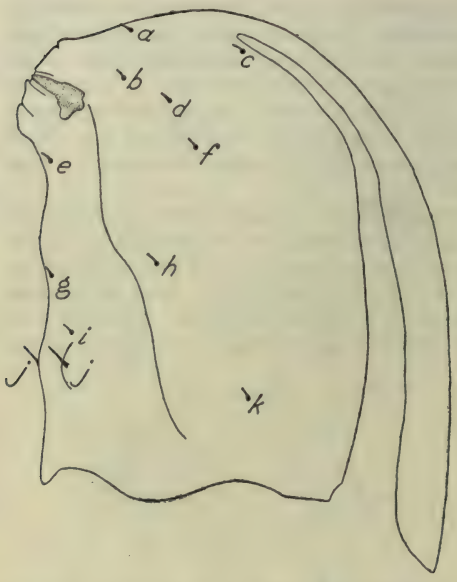


FIGURE 4.—Lateral view of head of first-instar larva of *Cremastus flavoorbitalis*, showing placement of spines.

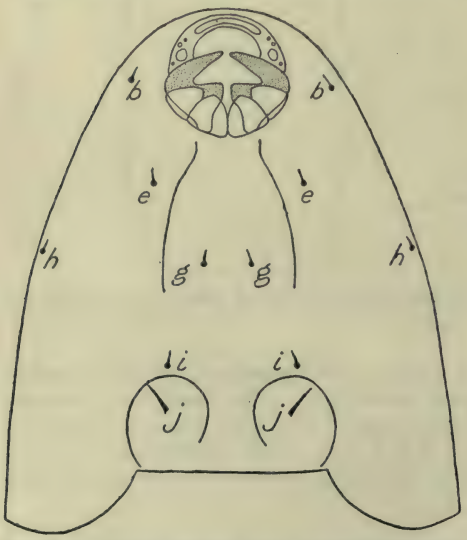


FIGURE 5.—Ventral view of head of first-instar larva of *Cremastus flavoorbitalis*, showing placement of spines.

ments. The cuticle is void of spines or other large processes, but is composed of many fine tubercles. The tail is still further reduced (fig. 7, *C*).

The terminology used in this bulletin in relation to the nomenclature of the structures of the head follows that of Vance and Smith (*11*). The detailed description follows.

Head hemispherical, thinly sclerotized, generally creamy white in color, and covered with many short protuberances; antennal fossae large, lightly sclerotized; metopic suture present; frontal region not well differentiated into a labrum; bilobed near oral cavity; two labral sensillae present; four papillae on frontal region, two dorsolaterad of the sensillae, two on the lobes in the oral cavity; superior pleurostomal ramus short, lightly sclerotized and lightly pigmented, brown; genal region possessing six regularly arranged setae; hypostoma heavily sclerotized, deeply pigmented, brown, blunt at lateral end, narrow, becoming wider at junction of stipital sclerome and inferior pleurostomal ramus; inferior pleurostomal ramus short, narrow, becoming wider at juncture of hypostoma and stipital sclerome; stipital sclerome narrow, becoming wider at junction with hypostoma; maxillary sclerome curved, blunt, heavily sclerotized, brown, thick near inner end, suddenly becoming thin, connecting with hypostoma at lateral end; maxillary region possessing a palpus and two definitely arranged setae; silk duct opening U-shaped, lying directly ventrad of oral cavity; one pair of labial palpi and two pairs of setae present in labial region, which is surrounded by a thickened border; border heavily sclerotized in dorsal portion, becoming less so at ventral portion; three definitely arranged setae present on labiobase on each side of thickened border (fig. 8); mandible simple, sickle-shaped, bearing no spines or teeth (fig. 7, *D*).

The third larval instar is 2 days in duration.

COCOON

The cocoon of *Cremastus flavoorbitalis* is oblong oval in shape and on an average measures 8.85 mm in length and 3.34 mm in width. There is, however, a marked variation in the dimensions of cocoons, the range being from 7 to 10 mm in length and from 2.5 to 4 mm in width. The coloration of the cocoon is not constant, as it varies from tan to dark brown. In most cases there is a lighter narrow band about the middle. Some cocoons, however, are without this faint marking. The cocoon (pl. 1, *D*) is enveloped in a loose but finely woven silk sheath (pl. 1, *E*). The average length of the period spent in the cocoon is 10 days.

PREPUPA AND PUPA

Cremastus flavoorbitalis spends the first 3 days of its cocoon existence as a prepupa of the usual hymenopterous type.

At the time of molting, the pupa is nearly white, with the exception of the darkened eye spots. In the course of several days the pupa darkens, and a few days before eclosion it takes on the markings and general appearance of the adult insect. The male pupa is generally smaller than the female. The ovipositor of the female extends beyond the tip of the abdomen and lies flat against the dorsal surface.

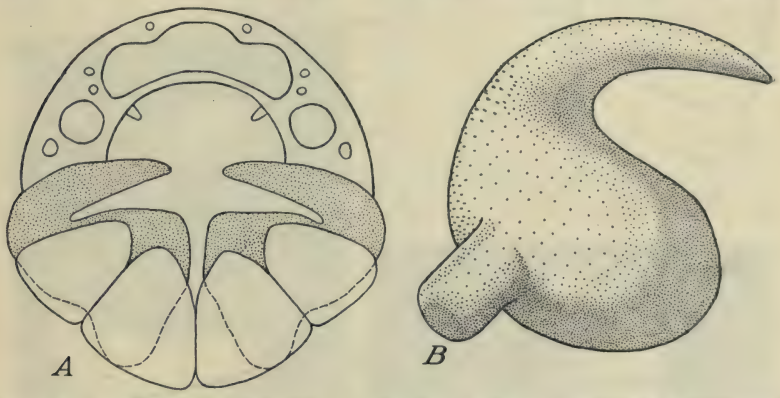


FIGURE 6.—*A*, Mouth-part structure of first-instar larva of *Cremastus flavoorbitalis*; *B*, mandible of first-instar larva.

BIOLOGY

HATCHING, GROWTH, AND DEVELOPMENT

While instances have been noted in which as many as five eggs of *C. flavoorbitalis* have been deposited in a single host, in no case has more than one larva of the parasite been known to develop beyond the first instar. The mechanics of this mortality of the supernumerary individuals is not known. However, in the case of these larvae, phagocytosis usually takes place immediately after they have hatched from the eggs. This condition was reported by Thompson and Parker (*10*) in connection with *Eulimeria crassifemur* (Thomson), another ichneumonid parasite of the European corn borer. It is

thought that in the case of *Aphidius* larvae (*5*) the first parasite to emerge from the egg emits a cytolytic enzyme that affects the younger larvae as well as the tissues of the host itself, thereby eliminating the extra individuals. Muesebeck and Parker (*4*, *p. 344*), in connection with *Hyposoter disparis* Viereck, a parasite of

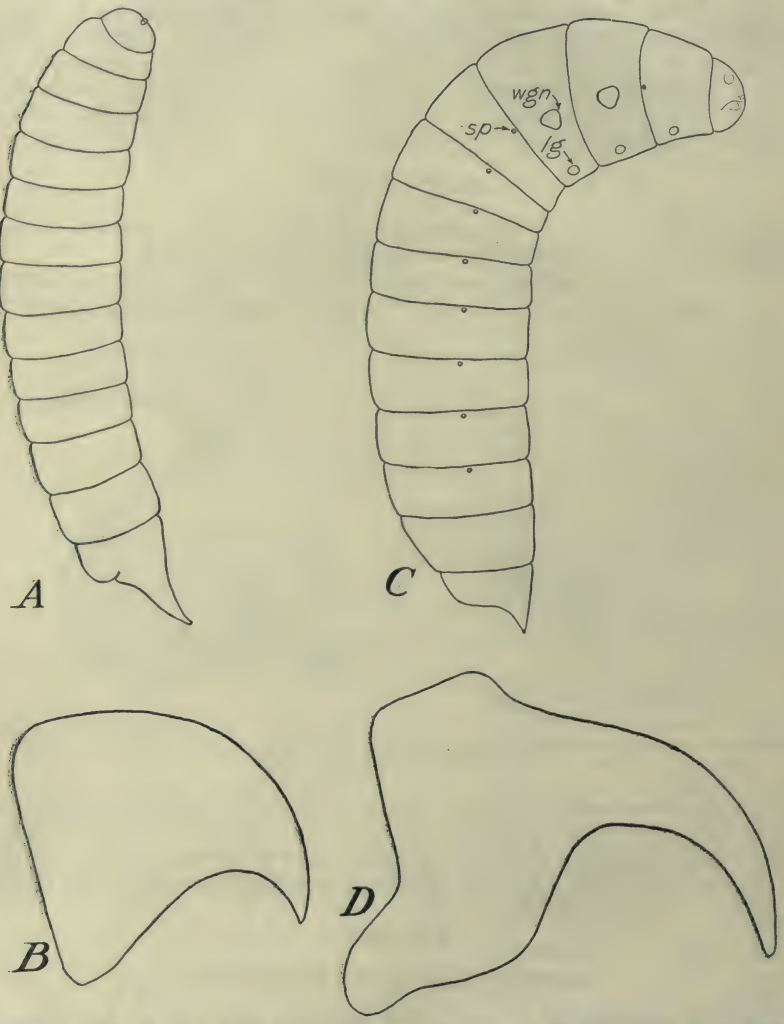


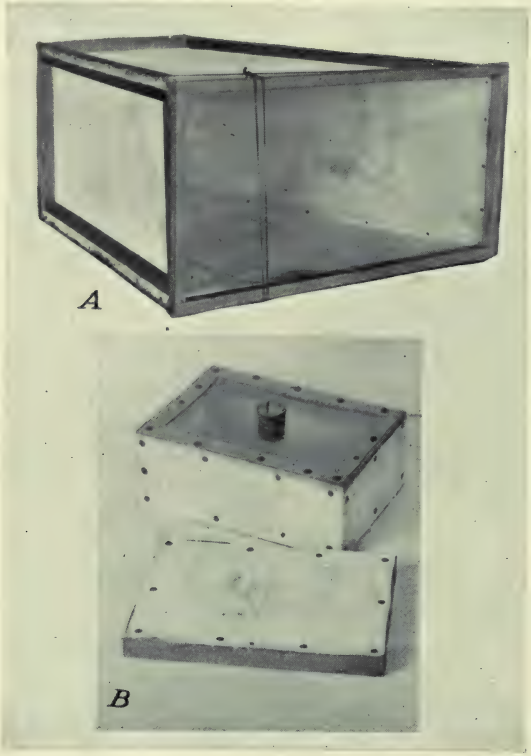
FIGURE 7.—Second- and third-instar larvae of *Cremastus flavoorbitalis: A*, Second-instar larva, ×20; *B*, mandible of second-instar larva; *C*, third-instar larva, ×8; *lg*, leg bud; *wgn*, wing bud; *D*, mandible of third-instar larva.

the gypsy moth, suggest that the egg or larva dies apparently before encystment occurs because the medium in which the parasite finds itself is not altogether suited to its development.

The egg floats freely within the body cavity of the host and hatches after 3½ days. The presence of the larval parasite in the body of

ADULTS, LARVA, AND COCOONS OF CREMASTUS FLAVOORBITALIS.

A, Adult male, ×5. *B*, Adult female, ×5. *C*, Third-instar larva of parasite after issuance from a larva of *Pyrausta nubilalis*, with remains of host, ×3. *D*, Cocoon, with silken sheath removed, showing exit hole of adult, ×5. *E*, Cocoon with attached head capsule of host larva, ×5.



CAGES USED IN EXPERIMENTS WITH CREMASTUS FLAVOORBITALIS.

A, Cage used for mating studies. *B*, Cage used for oviposition studies.

the host seemingly has no effect on the physical condition of the borer while the parasite is small. For 5 days the larva remains in this instar, changing in body form, as has been indicated elsewhere in this bulletin. The second instar lasts but 1 day. One day after the parasite has molted into the third instar, the host larva spins a loose web, attaching itself to any convenient surface, and reclines in a characteristic hammocklike position and remains quiescent. It then begins to darken at both ends, and this blackening steadily progresses toward the center of the larva. When the host has become completely darkened, usually 2 days after the molt of the parasite into the third instar, the *Cremastus* larva makes its first appearance on the outside,

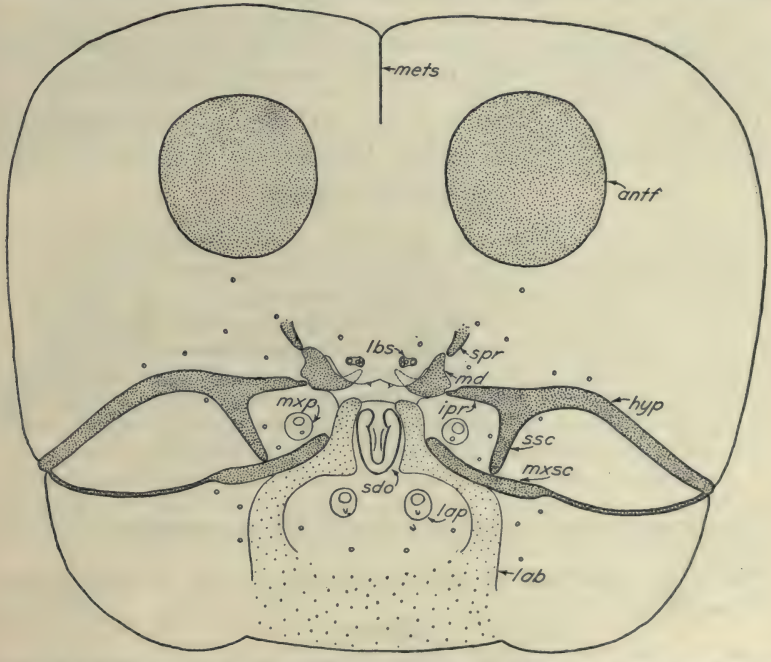


FIGURE 8.—Head structure of third-instar larva of *Cremastus flavoorbitalis*: *antf*, antennal fossa; *hyp*, hypostoma; *ipr*, inferior pleurostomal ramus; *lab*, labiobase; *lap*, labial palp; *lbs*, labral sensillae; *md*, mandible; *mets*, metopic suture; *mxp*, maxillary palp; *mxsc*, maxillary sclerome; *sdo*, silk duct opening; *spr*, superior pleurostomal ramus; *ssc*, stipital sclerome.

emerging through a hole in the middle of the host. There is no external feeding.

European corn-borer larvae parasitized by *Cremastus flavoorbitalis* are usually smaller than the nonparasitized larvae, at least a few days prior to the issuance of the parasite larva from the host. Head measurements of larvae after the parasite had left the body would seem to indicate that the host larvae were in the fourth instar. This is probably incorrect. In the case of larvae parasitized by *Chelonus annulipes* it was found that the head capsules were distinctly smaller than those of nonparasitized larvae of the same instar. It is possible to assume, then, that the host larvae are in the fifth instar at the time that the parasites issue from the hosts.

The larva immediately upon issuance (pl. 1, *C*) begins to spin a cocoon, cementing it to any nearby surface. The head capsule and the dried-up body of the host larva (pl. 1, *E*) are usually attached by a few loose threads. When the operation of cocoon spinning is completed, the parasite is in the prepupal stage and stays as such for 3 days; then it expels the larval meconium and molts into a typical white hymenopterous pupa. The pupa gradually develops and darkens for 7 days, at which time the adult sheds the pupal skin, chews an irregular hole at one end of the cocoon (pl. 1, *D*), and emerges.

At Kobe, Japan, C. A. Clark[3] found that in the laboratory the life cycle was about 26 days in July and August.

Adults were kept in wooden cages, each cage containing a piece of lump sugar, fastened to a glass slide by means of a drop of melted beeswax. (The cages when not in use were kept in a cool cellar and covered with moist burlap.)

The maximum recorded longevity of *Cremastus* adults under laboratory conditions was 66 days. The average longevity was 38.78 days.

HABITS OF THE ADULT

The adult of *Cremastus flavoorbitalis* is quite positively responsive to light, is very active, and exhibits a restless temperament. When several adults are placed in a cage, especially if it is small, their activities in trying to escape are very pronounced. In several instances in mating studies, adults were introduced into a specially prepared cellophane cage, but their efforts to beat their way through the sides of the structure were so frantic that the use of these cages had to be abandoned. When first introduced into cloth-covered cages, although noticeably irritable, they calm down in a few minutes and content themselves with incessant ramblings over the end of the cage nearest the light. At temperatures below 70° F. they are quiescent and do not become active until the temperature rises above that point.

The adults will feed on sweetened water, honey, or invert sugar, such as glucose.

MATING

In the rearing of *Cremastus flavoorbitalis* in the laboratory, the problem of mating in captivity was the most difficult one encountered. Many attempts were made to overcome this so that it might be possible to rear this parasite in large numbers.

Matings were secured in abundance on only one occasion, on July 2, 1931. At that time 75 males and 65 females were introduced into a cloth mating cage. This cage (pl. 2, *A*) is 9 inches in height, 18 inches in width at the open end, and 18 inches in length, tapering toward the front or closed end, which is 9 by 9 inches. The open back is equipped with a 9- by 18-inch celluloid-covered frame, which is held in place by elastic bands.

The cage was placed on a table in a third-story room, so that the small end was facing a closed window and no direct sunlight shone

[3] C. A. Clark, assistant entomologist, Bureau of Entomology, United States Department of Agriculure, was in charge of European corn borer parasite investigations in the Orient from the fall of 1930 to the spring of 1932.

on the cage. The temperature inside the cage was 74° to 76° F. On the outside it was 82° F. This cage was dampened, and sand was placed in the bottom of it, before the parasite adults, which were 2 days old, were introduced. Almost immediately after admission to the cage, the parasites began to show some attraction for each other, although this had not been observed before. When the cage had become nearly dry, one mating occurred. The sides of the cage were again moistened with a sprayer and a stream of air allowed to enter the rear of the cage in such a way that the insects received only a part of the effect of the breeze. This aeration was continued for 5 minutes and then stopped. For 5 or 10 minutes thereafter matings occurred in such rapid succession that it was extremely difficult to remove the mated females.

Experiments were made to discover whether foods other than sugar, different temperatures, different lights, or different times of day had any effect on the mating of *C. flavoorbitalis*, but only occasional matings occurred.

The mating preliminaries are very brief and mating itself lasts from 1 to 5 minutes. During mating a pair may be greatly disturbed without the act being interrupted.

D. W. Jones, of the Arlington, Mass., laboratory, states that *Cremastus flavoorbitalis* sometimes mates very readily immediately after the cover of the liberation can has been removed and the insects have flown out into the open. This experience suggested that perhaps the insects would mate if they were not confined to a small place, but observations of specimens in the emergence cages, which have a screen area of approximately 32 square feet, indicated that apparently this had no bearing on the problem. What the determining factor is that controls the mating instinct in this particular parasite is problematical.

OVIPOSITION

The cage (pl. 2, *B*) used in this study of oviposition consists of a wooden framework 2 by 4 by 5½ inches, covered with cloth on the sides. The top is of celluloid and contains a hole in the center, which is closed with a stopper. The bottom, which is detachable, consists of a 4- by 5½-inch wooden frame on which either cloth or celluloid has been tacked. The celluloid-covered bottom is considered more satisfactory because the borers do not make holes in it as readily as they do in cloth. This whole equipment is held together by means of elastic bands.

The cage was prepared for use by placing a thin layer (one-eighth inch) of finely diced peas on the detached bottom of the cage. It was then fastened together with the bands, care being taken that the peas remained in their original position. Ten-day-old incubator-reared host larvae were then inserted through the opening in the top of the cage and the stopper was replaced. This whole equipment was placed in the incubator (regulated for 80° F. and 70 percent relative humidity) overnight to allow the borers to become webbed up in the peas. It is possible to prevent the wandering of the larvae from the pea stratum on the bottom by placing the cage in a glass-bottomed cabinet so that the light reaching the cage comes through the bottom only.

The following morning the cage was removed and five mated *Cremastus* females were introduced into it through the entrance hole in the top. At this time the host larvae were in the fourth instar. The cage was then placed on a table near a window or on a window sill in such a way that the light reached the inside of the cage through the bottom.

Almost immediately upon their entrance to the cage the parasite females begin to crawl about the webbed-up peas and dry frass, intensely interested in what lies beneath. During this meandering they continually beat the peas with their antennae and prod here and there with their ovipositors. An ovipositing female has been observed to prod a webbed-up, frass-covered pea, from which the borer had escaped, just as readily as one that contained a borer, whereas a free-crawling borer rarely incited her curiosity. However, a few cases have been noted in which oviposition apparently has taken place in free-crawling larvae. When the parasite locates a corn-borer larva in its webbing she stabs it but once with her ovipositor. All of the ovipositions noted were made in the thorax of the host larva immediately behind the head capsule. After accomplishing oviposition the parasite walks away, continually beating and prodding in search of another victim. The attacked borer thrashes its head back and forth, apparently in a vain effort to rid itself of the parasite egg.

Oviposition experiments were tried on the fall webworm (*Hyphantria cunea* Drury), the pitch-pine webworm (*Tetralopha robustella* Zell.), and several undetermined webworms and borers, with no success.

SEX PROPORTIONS

The proportion of sexes in *C. flavoorbitalis* in samples of material sent from the Orient for parasite liberations in this country, covering a period of 2 years, is 62.1 percent females and 37.9 percent males. On the other hand, in material bred in the laboratory the percentages are about reversed, there being 68.5 percent males and only 31.5 percent females. The latter figures are based on material that was reared from apparently mated females. It is thought that this situation might arise through the difficulty in mating the parasite in captivity, since unfertilized females produce males only.

SEASONAL HISTORY

This parasite was shipped from the Orient to the Arlington, Mass., corn-borer laboratory during the winter as well-developed first-instar larvae within the mature corn-borer host larvae. These shipments reached this country under refrigeration in the ship's vegetable storage room, where the temperature range was 35° to 40° F. During the remainder of the winter they were stored in an underground cellar, where the temperature range was 32° to 45°, later gradually rising to nearly 55°, when the use of ice became necessary to keep the temperature below this point. The relative humidity in this cellar was kept above 90 percent.

On March 7, 1932, a sample lot was taken from refrigeration to determine the development of the species in the United States at Arlington, Mass. Dissections were made biweekly until the first of June, after which time they were made every other day. All dissections made before July 1 showed the parasite larvae to be in the

first instar. In July, however, all stages of development (first-, second-, and third-instar larvae, cocoons, and adults) were found in the material, showing that the stages beyond the first larval instar are so short in overwintering *Cremastus* that it would be possible to find all stages in the field at one time after they had started to develop.

It is not definitely known how many generations occur or when hibernation begins. C. A. Clark says:

> Winter is usually passed as immature larvae inside the overwintering corn-borer larvae, but apparently a small number pass the winter in the cocoon stage. Examination of a number of cocoons collected in the field in the Kokubu section in February 1932 proved that not all of the individuals of this species were in the host larvae. Most of the cocoons were empty, the adults probably having emerged in the late fall months, but a few live *flavoorbitalis* larvae were found, as well as one live pupa (February 18, 1932). The first spring cocoons were found on May 3 in Miyakonojo section in 1931 and by the middle of May cocoons became numerous in the fields here. In Kumamoto section a full spring generation of the parasite has been passed on *nubilalis* larvae by the end of June. Hyperparasites * * * somewhat reduce its effectiveness * * *. The parasite is usually recovered in numbers from overwintering borers in millet and from first summer-generation borers on hemp on Kyushu Island. It seems to be most important in the spring, but other species (*Macrocentrus gifuensis* Ashm. and *Ceromasia lepida* Meig.) apparently take its place later in the summer.[4]

DISTRIBUTION

Cremastus flavoorbitalis is widely dispersed in the Orient. It is known to occur in Banjo in the northern part of the peninsula of Chosen; in Kumamoto, Oita, Miyazaki, Kokubu, and Kagoshima, on the island of Kyushu; in Tokushima on Shikoku Island; at Chiba, Tochigi, Utsunomiya, and Hiroshima, on the largest island of Japan, Honshu.

Cremastus flavoorbitalis is of most importance in Kumamoto, Kokubu, and Miyakonojo sections, but is also found in considerable numbers in Utsunomiya and Hiroshima sections, where it is of some value as a *nubilalis* parasite. It seems to be of particular importance as a parasite in Kumamoto section, where parasitization of over 30 percent has been recorded, though the average parasitization is considerably lower than this.

It has been recorded (*3*) in India from Pusa, Chapra, and Katihar, Bengal; Deesa and Surat, Bombay; Quilon and Travancore, Madras; Trincomali and Peradeniya, Ceylon; and Bhamo, Burma. Specimens were also taken on shipboard 4 miles off Tuticorin and 10 miles off Coconada, Madras coast.

There are specimens in the national collection (*2*) from Japan, Hawaii, and the Philippines, and in the Baker collection from Singapore.

This species was probably introduced into Hawaii, as it was unknown there until 1910 (*7*). It appeared first in the lowlands but has now spread to the mountains and all over the island of Oahu.

This parasite has been liberated in the United States and Canada. The names of the places, the seasons of liberation, and the number of parasites released, are given below.

Massachusetts: Arlington, 1930, 2; 1932, 15; total, 17. Saugus, 1929, 220; 1930, 371; 1931, 18; total, 609. Bridgewater, 1931, 1,660; 1932, 1,488; total, 3,148. Swansea, 1932, 1,668. Medford, 1932, 593. Peabody, 1932, 705.

[4] From Clark's unpublished report on corn-borer work in the Orient.

Rhode Island: East Providence, 1929, 116; 1930, 16; total, 132. Portsmouth, 1932, 522; 1933, 360; total, 882.
Connecticut: East Lyme, 1929, 25; 1930, 93; 1931, 203; 1932, 315; total, 636.
Ohio: Jerusalem Township (Lucas County), 1932, 2,321; Damascus Township (Henry County), 1932, 2,824.
New York: Glenville, 1930, 276; Jamesport, 1933, 141; Eastport, 1933, 92.
Ontario, Canada: Belleville, 1932, 1,371; 1933, 160; total, 1,531.
Total by States and Provinces: Massachusetts, 6,740; Ohio, 5,145; Rhode Island, 1,014; Connecticut, 636; New York, 509; Ontario, 1,531. Grand total, 15,575.

In 1931, 141 *Cremastus flavoorbitalis* were sent from Japan to Guam but probably were not liberated.

The first recovery of this species in the United States was made at Saugus, Mass., in 1929. It was also taken at Providence, R.I., the same year. In 1931 the species was taken at Bridgewater, Mass. In 1932 it was recovered in Lucas County, Ohio, and in fair numbers in the greater Boston area, showing successful initial establishment.

SUMMARY

Cremastus flavoorbitalis (Cameron) is an oriental ichneumonid parasite of the European corn borer. In Hawaii it has a large number of hosts and is instrumental in the control of the coconut leaf roller and the sugarcane leaf roller.

The adult is a yellowish wasplike insect about one-third of an inch in length. The egg is pearly white, elongate-ovoid, and bears no spines or external processes. The duration of the egg stage is 3½ days. The first larval instar lasts 5 days. The primary larva has a long tail. One day after hatching the larva presents a ruffled or "scalloped" appearance, two rows of scallops to every segment. One day later this ruffle has nearly disappeared, and on the fifth day it has disappeared entirely, and the body has become robust. The head of the first-instar larva is thimble-shaped and bears several well-defined spines and setae. The mouth parts are well developed. The second larval instar lasts but a day. The tail has been reduced in length to become a very short process. The head is rounded and thinly sclerotized. The mandibles are triangular and lightly sclerotized. The mature larva has 13 body segments. Spiracles are found on the first thoracic and first 8 abdominal segments. The tail is still further reduced. The head and mouth parts are well differentiated. Mandibles are simple and sickle-shaped. This instar lasts 2 days. The cocoon is usually grayish tan with a lighter band about the middle. It is enveloped in a finely woven silk sheath. The time spent in the cocoon is 10 days. During the first 3 days of this period the insect is a prepupa. The newly formed pupa is nearly white.

The egg is laid in the body of the host larva and floats freely within its walls. While as many as five eggs may be deposited, only one develops beyond the first stage. One day after the parasite molts to the third instar the host larva spins a loose web, attaches itself to a convenient surface in a characteristic hammocklike fashion, and commences to turn dark from the ends toward the middle. The *Cremastus* larva makes its appearance through a hole in the middle portion of the host during the late fifth instar of the host. The parasite larva immediately begins to spin its cocoon.

After shedding its pupal skin, the adult emerges through an irregular hole at one end of the cocoon. The adult is positively phototropic, very active, and very restless. Adults fed on sweetened water, honey, or glucose. The maximum recorded longevity is 66 days. The insect does not mate readily in captivity. Females oviposit readily in spun-up corn-borer larvae of the fourth or early fifth instar. Ordinarily they do not deposit eggs in free-crawling borers.

Parasites reach this country in the winter as well developed first-instar larvae within the overwintering borers. Under natural conditions they emerge as adults during the first part of July at Arlington, Mass.

Cremastus flavoorbitalis is widely dispersed in the Orient. It is found quite generally in the Hawaiian Islands. It has been liberated in sections of Massachusetts, Rhode Island, Connecticut, New York, Ohio, and Ontario, and has been recovered from the greater Boston area in Massachusetts, from Providence, R.I., and from Lucas County, Ohio.

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SHRINKAGE AND HEAT PENETRATION DURING THE ROASTING OF LAMB AND MUTTON AS INFLUENCED BY CARCASS GRADE, RIPENING PERIOD, AND COOKING METHOD[1]

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INTRODUCTION

To the meat producer as well as to the consumer the cooking qualities of the different market grades are important. With lamb and mutton as with other meats, the thickness of the fat covering on a carcass is one of the chief points in determining grade. The grower of course tries to put the right degree of finish on his lambs so they will be neither too fat nor too thin. Grade is a matter of dollars and cents to him when he figures up his production costs and sells his lambs. But even for the grower the economic importance of grade does not end there. He needs to know for instance how much weight his very fat lamb loses in cooking and how much time is required to roast very small thin lamb. For in the long run such points make an impression on consumer demand and react on market prices.

[1] See Statement of Cooperation, p. 26.

[2] Prepared in consultation with other members of the U.S. Department of Agriculture publication committee of the cooperative meat investigations, O. G. Hankins (chairman), L. B. Burk, Paul E. Howe, H. C. McPhee, D. A. Spencer, and K. F. Warner. Acknowledgment is made to Elizabeth A. Engstrom and Meda K. Gates for laboratory and statistical assistance and to Lillian M. Grigg and Esther M. Lyerly for statistical assistance.

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As for consumers themselves, the value of such information to them is obvious. All classes—from hotel and restaurant keepers, to dietitians in institutions, to homemakers buying food for their own families—need definite facts on the selection and cooking of meats. Information that relates the finish of the raw cut to shrinkage of the cooked meat and time in the oven is part of the scientific basis of such a guide.

To distributors of dressed meat, and also to institutional managers who buy in large quantities and store in their own coolers, the effect of ripening or aging on cooking qualities of meat is a matter of interest. It is, of course, well known that ripening meat for several days makes it more tender. That ripening influences cooking shrinkage and the speed of cooking is not so well known, but it is also of economic importance in the handling of meat.

To research workers in meat cookery, knowledge of the influence of finish and ripening on shrinkage and speed of cooking is essential because these factors are inseparable from the meat itself. Unless research workers know how the character of meat affects its shrinkage and the rate of heat penetration, they cannot judge the merits of different methods of cooking and make sound recommendations to homemakers, institutional cooks, and manufacturers of cooking equipment. The fact that 750 legs of lamb roasted by one standard method showed a range in shrinkage from 7 to 25 percent of the weight of the raw meat, and in cooking time from 25 to 58 minutes per pound, is striking proof of the difference made by the character of the meat itself.

This bulletin represents an initial attempt to supply much-needed information on the factors that influence shrinkage and rate of heat penetration during roasting. It presents data on 7 different methods of roasting 1,185 legs of lamb and mutton, ranging in grade from Choice to Cull, and in ripening period from 2 to 24 days after slaughter. Included also are chemical analyses of 30 legs of lamb from Choice to Cull grade carcasses contributed by the Animal Husbandry Division of the Bureau of Animal Industry. Without attempting refined correlation methods these data were used as a basis for estimating what shrinkage may reasonably be expected and how much time to allow for roasting leg of lamb or mutton of a given grade and a certain ripening period when using a particular method.

The meat for these experiments was obtained through the cooperative meat investigations,[3] a national project which affords a unique opportunity to study a large number of samples from animals of known history grown, slaughtered, chilled, and stored under controlled conditions. A large proportion of the meat samples was cooked by one standard method for palatability tests in connection with production experiments, and additional meat samples were used for the studies of cooking methods.

REVIEW OF LITERATURE

Although research in meat cookery has been under way in the United States for more than 30 years a review of the literature discloses no information on the shrinkage of lamb and mutton roasted

[3] UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF ANIMAL INDUSTRY. A STUDY OF THE FACTORS WHICH INFLUENCE THE QUALITY AND PALATABILITY OF MEAT. 76 pp., illus. 1927. [Mimeographed.]

by controlled methods up to 1931 when Weber, Loeffel, and Peters (*7*)[4] published data on the shrinkage and cooking time of 66 legs of lamb all roasted by the standard method used in the cooperative meat investigations.[5]

These authors reported high correlation between carcass grade and fat content as indicated by analysis of the wholesale cut commonly referred to as the rack. The lamb carcasses of Choice grade showed on the average 44 percent fat in the rack; of Good grade, 35.5 percent; of Medium, 30.5 percent; of Common, 28 percent. There was, however, considerable variation within each grade, the data showing ranges of 15 percent in any grade and 30 percent in the Medium grade.

The cooking data reported by Weber and his associates show a range from 5.89 to 9.41 percent in evaporation losses, with most of the values falling between 8 and 9 percent. Drippings losses ranged from 3.03 to 7.83 percent and cooking time from 27 to 33 minutes per pound. These investigators concluded that while losses by evaporation bear no definite relation to the fatness of lamb, drippings losses are directly related to fatness—the fatter legs shrinking most—and that the cooking time per pound is slightly less for the fatter legs. Unfortunately they did not publish data on the shrinkage and cooking time of lamb of stated levels of fatness or of grade designation.

EXPERIMENTAL PROCEDURE

HISTORY OF SAMPLES

With the exception of nine pairs of lamb legs purchased in Washington, D.C., markets, all the samples discussed in this bulletin came from animals raised at Federal agricultural experiment stations or at the State agricultural experiment stations of Indiana, Maryland, Mississippi, New Mexico, New York (Cornell), Tennessee, and West Virginia.

For every animal raised in the experiment stations there was a record kept of breed, sex, age, and feeding ration. In all, the 1,167 legs of lamb and mutton of known history that were cooked represent 11 breeds. As to sex there were rams, wethers, and ewes. The lambs varied in age from 4 to 12 months. Nineteen different feeding rations were used.

After the animals were slaughtered, the carcasses were graded in accordance with the standards established by the Bureau of Agricultural Economics (*1*). In a total of 938 lamb carcasses there were 213 of Choice grade, 463 of Good, 171 of Medium, 41 of Common, 22 of Cull, and 28 of unrecorded grade. The nine mutton carcasses were distributed by grades as follows: Choice, 2; Good, 3; Medium, 3; Common, 1.

The legs of lamb and mutton were removed from the carcass where they joined the loin or just forward of the external angle of the ilium. They were then sawed apart, trimmed, and shaped up as if for the retail market. The fell was not removed.

The period of ripening the meat after slaughter ranged from 2 to 24 days, but most of it was aged from 4 to 9 days. Wide variation in ripening period was unavoidable in cases where as many as 100 or

[4] Italic numbers in parentheses refer to Literature Cited, p. 25.

[5] UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF HOME ECONOMICS AND BUREAU OF ANIMAL INDUSTRY. METHODS OF COOKING AND TESTING MEAT FOR PALATABILITY. 36 pp., illus. 1933. [Mimeographed.]

more lambs were slaughtered at a time, and a leg from each set aside for palatability tests, because the capacity of the cooking and judging laboratory was limited to eight legs a day. A special study of the effects of varying the period of ripening was made on paired legs from the same carcass in which one leg was cooked shortly after slaughter and the other leg held back for longer ripening.

ROASTING METHODS

All the legs of lamb and mutton were roasted by one of the following seven methods, differing from each other in oven temperatures and in the stage of doneness to which the meat was cooked as shown by a roast-meat thermometer.

Roasting method 1. By far the greatest number of samples was roasted by the standard laboratory method adopted for leg of lamb in connection with the cooperative meat investigations, since the meat was cooked for palatability tests as part of production experiments. According to this method, here designated as method 1, the leg of lamb or mutton was prepared for the oven without salt, pepper, or flour. Each leg was weighed, and then laid with the cut-flesh and pelvic-bone side up and the skin side down on a wire rack in a weighed roasting pan. A roast-meat thermometer was inserted to the center of the thickest portion of each leg and kept there throughout the cooking to show when the desired stage of doneness was reached. The leg, prepared in this way, was seared for 20 minutes at an average oven temperature of 265° C. after which the cooking was continued at 125° until the meat thermometer registered 76°, when the leg was removed from the oven and weighed. The meat was roasted entirely without a lid and without water added to the pan. The slow finish at 125° yields a uniformly cooked product deemed especially desirable for judging.

The other methods of roasting, held in most cases to be better adapted to household conditions, were based on method 1 but with the exception of method 7 varied from it in the use of higher oven temperatures or higher meat temperatures, resulting respectively either in faster cooking or more thoroughly cooked meat. At 76° C. lamb is between medium and well done and the juice is pink. Lamb is well done at 83° and is probably preferred this way by most people.

Roasting method 2. The meat was seared for 20 minutes at 265° C. as in method 1, but finished at 150°, to 76° internal temperature.

Roasting method 3. The meat was seared as in method 1 but finished at 175° C., to 76° internal temperature.

Roasting method 4. The meat was roasted at 175° C., without searing, to 76° internal temperature.

Roasting method 5. The meat was either seared as in method 1, or for 35 minutes at 250° C., and finished at 125°, to 83° internal temperature.

Roasting method 6. The meat was seared as in method 5 but finished at 175° C., to 83° internal temperature.

Roasting method 7. The meat was roasted at 125° C., without searing, to 76° internal temperature.

For all experiments the ovens were gas heated, indirect in action, ventilated, equipped with glass doors and temperature regulators. Portable thermometers in the same relative position in the several

ovens registered the oven temperatures, which were read through the glass doors.

The rate of heat penetration was determined by the number of minutes per pound required in cooking. Total time in minutes includes the searing period. The number of minutes per pound was calculated by dividing the total time by the weight in pounds of the uncooked leg.

DETERMINATION OF COOKING LOSSES

In these investigations shrinkage is defined as loss of weight during cooking. The shrinkage of each leg was determined as total loss of weight, and also as two fractions of the total, namely, the pan-drippings loss and the loss due to evaporation of water. Total shrinkage is the difference between the weight of the leg before cooking and immediately on removal from the oven. Drippings loss is the weight of the mixture of fat and juice which cooks out of meat and collects in the roasting pan. Loss of weight due to the evaporation of water is the difference between total loss of weight and the weight of the drippings. Unless otherwise indicated the shrinkage of each leg was calculated as percentage of the weight of the raw leg, trimmed, with the fell left on, and including bone.

While loss of weight of meat during cooking has value as such and can be discussed without reference to its fractions, it is frequently desirable to know what constituents of the meat went into the make-up of the loss of weight and how the original composition of the meat was modified. The only way to do this with precision is by chemical analysis of the meat, raw and cooked, and of the pan drippings. Fortunately, considerable work of this type was done by Grindley and Mojonnier (*3*) and more recently by McCance and Shipp (*4*), and while not on roast leg of lamb, the outstanding results on cooking losses are applicable to any kind of roasted meat. On the basis of principles established through chemical analysis it is possible to discuss the evaporation and drippings fractions of the loss of weight as approximations to losses of the chief constituents of meat during roasting.

McCance and Shipp distinguish between "shrink" and loss of weight. They define shrink as reduction in volume brought about by the action of heat on meat proteins. According to these authors, the loss of weight of flesh (beef and fish) during roasting is made up of water, fat, protein, and salts. The loss of weight due to evaporation accounts for nearly all of the water lost during roasting in dry air, that is, in an uncovered pan in a ventilated oven. The rest of the water is lost by dripping into the roasting pan. The pan drippings contain also fat, salts, and protein, but the loss of salts and protein is a small proportion of the loss of weight when flesh is roasted in dry air according to the results of chemical analysis. Most of the loss of weight is therefore due to loss of water and of fat.

On comparing the cooking losses obtained by the writers' methods with those determined by chemical analysis it appears that the evaporation fraction of the loss of weight is less than the true water loss but is a reasonably good approximation to it. Pan drippings usually are mainly melted fat, but it is probable that the composition of the drippings varies considerably, hence this fraction of the loss of weight has no definition in terms of exact amounts of fat, water, protein, and salts. Although exactness cannot be claimed for losses of meat constituents determined as evaporated water and as pan drip-

pings, the writers believe that when applied to meat as it is cooked by practical methods, these rough estimates of the water and fat loss have more value than loss of weight alone as a guide to the changes in volume, nutritive value, and palatability brought about by roasting.

The reduction in volume of meat on cooking is of considerable importance because it affects the appearance of the cooked cut and the number of servings obtainable from it. According to McCance and Shipp, loss of weight during cooking is a close measure of reduction in volume only for very lean meat, for which the loss is mostly water. The ordinary roast of course contains fat as well as lean and, as is well known, loses water and also melted fat during cooking. The presence of fat complicates the relationship between loss of weight and reduction in volume. Although the volume of servable meat in a roast may not be reduced appreciably by the melting out of a considerable portion of the fat, it may be affected noticeably by the loss of water. In order then to form a picture of volume changes, estimates of fat and water fractions of the loss of weight are needed, even if close relationships are not to be expected.

For studying changes in nutritive value through cooking losses, insofar as this is possible, estimates of water and fat fractions of the loss of weight, though rough, obviously have merit. Water loss does not represent loss of nutritive value, but it does affect the concentration of constituents left in the cooked meat. In this connection attention is called to the limitations of indirect determination of the food value of a piece of cooked meat, since Grindley and Mojonnier (*3*) and also McCance and Shipp (*4*) state that little is known of the portion of the cooking losses contributed by skin and bone. Pan drippings made into gravies and sauces do not represent a loss of nutrients. Nevertheless under some circumstances it is desirable to know how much of the loss of weight went into pan drippings. This is particularly true when the drippings contain more fat than can be used. Under these conditions there is a loss of nutritive value. At the same time it is scarcely fair to attribute this waste to cooking because not all this fat would have been eaten even if it had been retained by the roast. Under any conditions excessively fat meat is wasty.

The palatability of a piece of cooked meat depends to some extent on its juiciness. Whereas loss of weight in itself may have little meaning as a guide to juiciness in determination of the palatability of meats, the evaporation fraction serves as an indicator of the quantity of juice, as at present judged by organoleptic tests.

PLAN OF EXPERIMENTS

When planning experiments to show the effect of grade of carcass, period of ripening, and method of cooking, on shrinkage and cooking time, everything possible was done to reduce the number of variables. In the studies of the influence of carcass grade the same cooking method was used on the same cut (the leg) from carcasses of different grades ripened to approximately the same extent. To show the influence of ripening or of cooking method, the meat samples were as nearly uniform as possible; that is, wherever possible paired legs from the same carcass were used, the left legs being treated one way and the right legs another. While such methods are tedious it is believed that they furnish the most information with the least

effort and that for comparing methods of cooking or otherwise handling meat, a small number of pairs is worth more than a much larger number of unrelated cuts. Preliminary to the tests on carcass grade, ripening period, and cooking method, 93 pairs of legs of lamb were cooked by method 1 to see how closely results on shrinkage and cooking time could be duplicated for the same meat, of the same ripening period, cooked by the same method.

Summing up, the order and arrangement of experiments were as follows:

1. Determination of allowance for error in data on shrinkage and cooking time as revealed by 93 pairs of lamb legs cooked by method 1.
2. Determination of the effect on shrinkage and cooking time of ripening 60 left legs of lamb 2 to 6 days and the 60 corresponding right legs 12 to 21 days, all cooked by method 1.
3. Determination of the effect of carcass grade on shrinkage and cooking time—first, for a large quantity of lamb grading from Choice to Cull cooked by method 1; then, for small groups of lamb of a range of grades cooked by methods 2, 3, 4, 5, and 6; and finally for mutton of several grades cooked by methods 1, 2, and 3.
4. Determination of the effect of cooking method on shrinkage and cooking time, using as far as possible pairs of legs of lamb and mutton for comparison of other methods with method 1.

EXPERIMENTAL ERROR IN DETERMINATION OF SHRINKAGE AND COOKING TIME

In order to decide from experimental data whether shrinkage and cooking time really are influenced by carcass grade, by ripening period, or by method of cooking, it is necessary first to determine what constitutes a significant difference in results. Of course, every determination of shrinkage and cooking time is subject to some error. It is, therefore, well to know how great this experimental error may be because unless differences between averages exceed their error they cannot be regarded as significant.

For a measure of error in the data the difference between duplicate determinations of shrinkage and cooking time was used. To make the duplicate determinations, corresponding left and right legs of lamb from the same carcass were cooked on the same day. Theoretically the right and left of each matched pair of lamb legs cooked on the same day by the same method should yield identical results. Where results are not identical the discrepancies are here regarded as due to error in the experiment. The study was conducted as follows:

The paired legs from 93 lamb carcasses were selected for the test. For each of 2 consecutive years the lamb was cooked by method 1 over a period extending from 5 to 18 days after slaughter. Data on shrinkage and cooking time were obtained separately for the left legs and for the rights. After cooking, the lamb legs were judged for palatability. Analysis of the data on palatability has been published by Spencer (*5*).

For each of the 93 pairs the difference between the left and the right leg was calculated on weight before cooking, shrinkage during cooking, and cooking time, and the differences averaged. For the 93 left legs and the corresponding rights the weights before cooking, the shrinkage during cooking, and the cooking time were averaged.

For each item, the difference between the averages was calculated and the standard error of the difference worked out according to the formula, $\sigma_M = \frac{\sigma}{\sqrt{n-1}}$ by the method which Fisher (*2, pp. 112–114*) quotes from "Student." The standard deviation, σ, is that of the series of differences between corresponding left and right legs calculated in the usual way as the root—mean—square of the deviations from the average of the series, and n is the number of samples used, 93. The data are presented in table 1.

TABLE 1.—*Comparison of determinations of shrinkage and cooking time on corresponding left and right legs of lamb, each pair ripened the same period, and all cooked by the same method (method 1: seared 20 minutes at 265° C., finished at 125°, to 76° internal temperature)*

Number and description of samples	Weight of uncooked leg	Shrinkage during roasting						Cooking time	
		Evaporation		Drippings		Total		Total	Per pound
	Grams	*Grams*	*Percent*	*Grams*	*Percent*	*Grams*	*Percent*	*Minutes*	*Minutes*
93, left	2,449	211	8.6	112	4.5	323	13.1	170	31.5
93, right	2,438	211	8.6	114	4.6	325	13.2	170	31.6
Difference	+11	0	.0	−2	−.1	−2	−.1	0	−.1
Standard deviation	±63.1	±41.2	±1.75	±24.6	±.967	±57.3	±2.39	±19.7	±3.98
Standard error	±6.6	±4.3	±.18	±2.6	±.10	±6.0	±.25	±2.1	±.42

According to Fisher two averages are not significantly different unless the difference between them is at least twice its standard error. In no case were the averages of the 93 pairs of duplicate determinations significantly different. However, according to the values found for standard errors in this study the averages of duplicate determinations of shrinkage and cooking time made on 93 pairs of legs of lamb could vary by chance alone up to 0.36 percent evaporation, 0.20 percent drippings loss, 0.50 percent total shrinkage, and 0.84 minutes per pound cooking time. These values are held to be significant differences between two averages, each of which is based on 93 samples.

Since 93 is an unusually large number of samples in experiments on cooking method, the standard errors for 20 and for 10 were calculated by dividing the standard deviations as found for the 93 by the square root of 19 and of 9, respectively. Following are the standard errors calculated for averages of 20 samples: Weight of uncooked leg, ±14.5 grams; weight lost by evaporation, ±9.5 grams, ±0.40 percent; weight lost by pan drippings, ±5.7 grams, ±0.22 percent; total loss of weight, ±13.1 grams, ±0.55 percent; cooking time, ±4.5 minutes, ±0.91 minutes per pound. For averages based on 10 samples, the calculated standard errors are as follows: Weight of uncooked leg, ±21.0 grams; weight lost by evaporation, ±13.8 grams, ±0.58 percent; weight lost by pan drippings, ±8.2 grams, ±0.32 percent; total loss of weight, ±19.1 grams, ±0.80 percent; cooking time, total ±6.6 minutes, ±1.33 minutes per pound. Allowance up to twice these standard errors should be made for experimental error when comparing averages based on 20 or 10 samples, respectively.

In generalizing from the results the writers realize that if data were available on an infinite number of groups of the composition of those studied, differences between duplicate determinations of shrinkage and

cooking time could not be expected to be exactly the same as those found in this experiment. At the same time these measures of experimental error are believed to be reasonable. They are useful throughout this bulletin as checks on the significance of differences to be ascribed to carcass grade, ripening, or method of cooking. Such checks are, of course, particularly helpful in judging the significance of results when averages are the only data reported, as frequently happens.

The experimental error as estimated may seem large. Much of the variation in shrinkage and cooking time between left and right legs was due to the manner in which they were shaped up as retail cuts, for if the fat covering over the inside round was stripped off more closely from one leg than the other there was a greater difference in the shrinkage and cooking time than when both were trimmed off to about the same extent. Slower cooking and increased shrinkage are direct results of excessive trimming. Apparently other factors also are involved in the differences between data from corresponding left and right legs cooked on the same day by the same method.

It is emphasized that this study covers but one method of roasting pairs of legs of lamb. Whether allowances for experimental error would need to be as large with other cooking methods cannot be stated but since the low oven temperature of 125° C. exaggerates the role of factors in the meat itself that retard heat penetration, smaller experimental error might be expected if higher oven temperatures were used.

SHRINKAGE AND RATE OF HEAT PENETRATION AS INFLUENCED BY PERIOD OF RIPENING OF THE MEAT

During the course of the study to determine experimental error in the data on shrinkage and cooking time, it became apparent that the length of time lamb legs are ripened after slaughter affects the cooking losses and the rate of heat penetration. Therefore, lest differences due to ripening be erroneously attributed to carcass grade or to cooking method, a special study was made of this.

Sixty pairs of lamb legs were chosen and the lefts cooked within 2 to 6 days after slaughter, while the corresponding rights were held from 8 to 18 days longer. All the legs were cooked by method 1 already described. The cooked meat was judged for palatability and the effect of ripening on the tenderness was reported by Warner and Alexander (*6*).

The data on shrinkage and cooking time for the corresponding left and right legs were handled as described on page 7, and the results are shown in table 2.

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TABLE 2.—*Effect of ripening on shrinkage and cooking time of pairs of legs of lamb, averaged for lefts and rights ripened for different periods, and all cooked by the same method (method 1: seared 20 minutes at 265° C., finished at 125°, to 76° internal temperature)*

Number and description of samples	Aging period	Interval between tests	Weight of uncooked leg	Shrinkage during roasting			Cooking time
				Evaporation	Drippings	Total	
	Days	*Days*	*Grams*	*Grams*	*Grams*	*Grams*	*Minutes*
3, left	4	8	1,927	192	69	261	166
3, right	12		1,871	154	78	232	154
3, left	3	9	2,420	270	159	429	208
3, right	12		2,271	175	102	276	184
8, left	3	10	2,379	264	143	406	207
8, right	13		2,363	209	132	341	193
8, left	4	10	2,114	220	113	332	181
8, right	14		2,095	203	108	311	181
8, left	6	10	1,880	178	87	265	160
8, right	16		1,806	160	81	240	152
8, left	2	17	2,338	256	144	401	191
8, right	19		2,122	152	117	269	151
8, left	3	17	2,250	217	117	334	189
8, right	20		2,024	174	94	268	156
11, left	4	17	2,025	197	91	287	173
11, right	21		1,832	137	82	218	140
3, left	3	18	2,424	251	134	385	193
3, right	21		2,222	155	126	281	169
Average (60, left)	4	13	2,171	223	115	338	184
Average (60, right)	17		2,042	169	101	270	162
Difference			+129	+54	+14	+68	+22
Standard error of difference			±13.4	±5.3	±3.1	±7.2	±2.5

Testing the significance of the differences between the averages of 60 left and 60 right legs, the value t (*2*) was calculated for each factor by dividing the difference by the respective standard error. Since in every case t exceeded 2.576 and since for samples larger than 30 only one value in a hundred will exceed 2.576 by chance, the differences between the averages are clearly significant.

On comparing the results in table 2 with those in table 1 it can safely be stated that longer ripening made the differences and that lamb lost less in weight during roasting and took less time to cook as the ripening increased. However, since the meat lost weight all the time it was in cold storage, there was less to cook the longer the ripening continued. This fact has to be considered in showing the effect of ripening on shrinkage as percentage of raw weight and on cooking time as minutes per pound.

To show the effect of so many days' additional ripening, as for example the average interval of 13 days in table 2, on the percentage of shrinkage and on the number of minutes per pound required to cook the lamb, the base should be the raw weight of the corresponding paired legs when the first set was cooked. The right legs were not weighed at the time the lefts were cooked. However, table 1 shows that left and right legs of lamb did not differ significantly in raw weight when the same ripening was given to both. So, for an approximation of the effect of 13 days' additional ripening as reflected in percentage of shrinkage during cooking, the average raw weight of 60

left legs ripened 4 days, namely 2,171 grams, was taken as the base for the 60 rights also, and the following results were obtained: Evaporation loss, 10.3 and 7.8 percent; drippings loss, 5.3 and 4.7 percent; total loss, 15.6 and 12.4 percent. Similarly, the cooking time as minutes per pound was reduced from 38 to 34 by the extra 13 days of ripening given to the right legs.

While this method of calculating brings out most forcefully that increased ripening reduces cooking shrinkage and cooking time, percentage of shrinkage and cooking time in minutes per pound are usually figured on the basis of the raw weight of a piece of meat at the time it is cooked. Comparing the relative shrinkage and rate of heat penetration of 60 left legs of lamb ripened 4 days and 60 corresponding right legs ripened 17 days on the basis of the raw weight of each group at the time it was cooked, respectively 2,171 and 2,042 grams, the following values were found: Evaporation loss, 10.3 and 8.2 percent; drippings loss, 5.3 and 5.0 percent; total loss, 15.6 and 13.1 percent; cooking time, 38 and 36 minutes per pound. This method of calculation also showed that as lamb was ripened longer it shrank relatively less during roasting and cooked faster in proportion to its weight.

The figures also showed a greater reduction in the evaporation loss during roasting than in the drippings loss as ripening progressed. This is reasonable because the meat dried out in storage and its water content became lower. When cooked, the 60 legs of lamb ripened 4 days weighed on the average 1,833 grams and the corresponding 60 ripened 17 days weighed 1,772 grams. The difference between the roasts when cooked, 61 grams, was less than before cooking, which was 129 grams.

SHRINKAGE AND RATE OF HEAT PENETRATION AS INFLUENCED BY GRADE OF CARCASS

For detailed studies on the influence of carcass grade on shrinkage and cooking time, the writers chose from production experiments a sample of 749 legs of lamb, including 168 of Choice, 389 of Good, 142 of Medium, 32 of Common, and 18 of Cull grade. From the statistical standpoint larger samples of Common and Cull grades would be preferable, but the production experiments yielded only a small proportion of lambs in these lower grades.

Included in this sample of 749 are 32 left legs from the 93 pairs in table 1, 13 lefts from the 60 pairs in table 2, 8 lefts from the pairs cited below, and 696 lefts not discussed elsewhere in this bulletin.

The ripening period for the 749 legs ranged from 2 to 24 days after slaughter, with from one-half to two-thirds of the legs ripened from 4 to 9 days and only one-seventh beyond 15 days. When averaged for the Choice, Good, Medium, Common, and Cull grades, the ripening periods were, respectively, 9, 10, 11, 10, and 10 days.

All 749 legs were cooked by method 1 already described. Data on shrinkage and cooking time averaged for the five different grades are given in table 3. The standard errors were calculated by the formula, $\sigma_M = \frac{\sigma}{\sqrt{n-1}}$. The standard deviation, σ, in this table is the square root of the sum of the squared deviations from the mean divided by the number of legs cooked, n.

TABLE 3.—*The effect of carcass grade on shrinkage and cooking time of legs of lamb when roasted to specified internal temperatures*

Carcass grade	Samples	Weight of uncooked leg	Shrinkage during roasting		Cooking time per pound
			Evaporation	Drippings	
	Number	*Grams*	*Percent*	*Percent*	*Minutes*
METHOD 1. OVEN: 265° C. FOR 20 MINUTES, 125° FOR FINISH. MEAT: 76°					
Choice	168	2,489±24.9	9.1±0.14	6.3±0.11	34.3±0.27
Good	389	2,250±27.8	8.9± .09	5.3± .07	34.1± .17
Medium	142	1,895±32.1	8.9± .14	3.7± .11	34.6± .27
Common	32	1,498±53.2	9.3± .29	2.3± .18	37.3± .72
Cull	18	1,117±58.9	10.2± .44	1.2± .09	40.9±1.38
METHOD 2. OVEN: 265° C. FOR 20 MINUTES, 150° FOR FINISH. MEAT: 76°					
Choice	1	2,285	10.8	8.3	27.0
Good	1	2,288	9.2	6.3	27.6
Common	2	1,412	11.4	2.8	31.9
METHOD 3. OVEN: 265° C. FOR 20 MINUTES, 175° FOR FINISH. MEAT: 76°					
Choice	2	2,556	10.8	7.1	20.2
Good	2	2,230	11.2	7.4	22.1
Medium	3	1,640	11.8	4.1	25.4
Common	1	902	11.2	1.6	31.2
Cull	3	1,027	11.8	1.3	26.4
METHOD 4. OVEN: CONSTANT AT 175° C. MEAT: 76°					
Choice	5	2,295	13.8	6.7	27.3
Good	5	2,236	14.5	6.5	28.9
Medium	7	1,791	13.6	5.7	29.4
Common	4	1,199	13.6	2.7	32.5
Cull	4	945	9.3	2.0	34.4
METHOD 5. OVEN: 265° C. FOR 20 MINUTES, 125° FOR FINISH. MEAT: 83°					
Choice	3	2,367	19.2	8.0	60.4
Good	5	2,050	18.8	7.7	64.4
METHOD 6. OVEN: 265° C. FOR 20 MINUTES, 175° FOR FINISH. MEAT: 83°					
Choice	3	2,349	18.7	8.2	26.9
Good	5	2,097	20.0	7.2	26.1

Additional tests of the influence of carcass grade on shrinkage and cooking time were made on smaller groups of both lamb and mutton, using other methods of cooking. The lamb legs of different carcass grades, cooked by method 2 were ripened for 4 to 5 days. Those cooked by method 3 were ripened, respectively, for Choice through Cull grades, 8, 8, 9, 7, and 7 days. Of the 25 legs of lamb cooked by method 4, 6 were purchased at a Washington, D.C., market and their ripening periods were not known, but for the remaining 19 the ripening periods averaged as follows: 4 Choice grade, 8 days; 3 Good, 8; 5 Medium, 9; 3 Common, 7; 4 Cull, 8. Of the lamb legs cooked by methods 5 and 6 those of Choice grade were ripened 8 days and of Good grade 7 days. Data are shown in table 3.

Table 4 presents the data for mutton of different grades cooked by methods 1, 2, and 3. Of those cooked by method 1, ripening periods averaged 7 days for the Choice grade, 7 for Good, 5 for Medium, and 5 for Common. Mutton legs cooked by method 2 were ripened 4, 5, 4, and 5 days, respectively, for Choice, Good, Medium, and Common grades. Ripening periods for mutton legs cooked by method 3 averaged 9 days for Choice grade, 8 for Good, and 6 for Medium.

TABLE 4.—*The effect of carcass grade on shrinkage and cooking time of legs of mutton when roasted to specified internal temperatures*

Carcass grade	Samples	Weight of uncooked leg	Shrinkage during roasting		Cooking time per pound
			Evaporation	Drippings	
	Number	*Grams*	*Percent*	*Percent*	*Minutes*
METHOD 1. OVEN: 265°C. FOR 20 MINUTES, 125° FOR FINISH. MEAT: 76°					
Choice	2	3,484	10.8	6.1	30.2
Good	3	3,146	10.2	4.0	27.6
Medium	3	2,746	13.0	3.1	32.7
Common	1	2,969	14.2	.4	34.4
METHOD 2. OVEN: 265° C. FOR 20 MINUTES, 150° FOR FINISH. MEAT: 76°					
Choice	1	3,537	14.0	8.1	28.2
Good	1	3,242	15.2	4.7	25.6
Medium	1	2,603	14.4	2.7	26.1
Common	1	2,846	20.9	1.0	27.1
METHOD 3. OVEN: 265° C. FOR 20 MINUTES, 175° FOR FINISH. MEAT: 76°					
Choice	1	3,256	14.8	6.7	18.0
Good	2	3,028	15.5	4.7	19.9
Medium	2	2,873	15.2	3.5	19.9

The significance of differences between the grades in the first section of table 3 was determined by the method of Fisher (*2, p. 108*). To compare any two means the standard errors were first squared to obtain the variances. In making use of the proposition that the variance of the difference of two independent variates is equal to the sum of their variances, the two variances were added. Then extracting the square root of this sum the standard error of the differences between the means was obtained, and from this t calculated as usual. For significant results t should be at least 2. In the other experiments reported in tables 3 and 4 the number of samples in each grade was very small, so the standard errors of the means were not calculated. Instead, the data for the different grades were examined to see if they seemed to show the same trend as the larger samples and then the differences between grades were roughly checked by comparing them with the allowances made for experimental error of 10 samples as determined on page 8.

With few exceptions, the data in tables 3 and 4 show the same general trend in the relation of carcass grade of lamb and mutton to shrinkage and cooking time independent of the method of cooking.

Drippings loss, in percentage, was definitely related to carcass grade. Choice grade lamb and mutton lost the most as drippings, and as the carcass grade became poorer the drippings loss decreased. In table 3, method 1, where there are many samples in each grade the decline in drippings loss was from 1 to 1.6 percent from grade to grade below Choice. These differences are significant, but the slight differences between drippings losses of Choice and Good grade lamb when cooked by methods 3, 4, and 5 are not in themselves significant.

Shrinkage due to evaporation loss was not consistently related to carcass grade. In table 3, method 1, the data show that Choice, Good, Medium, and Common grade lamb did not differ significantly in evaporation loss, but that Cull grade lamb lost slightly more. The next largest sample was the 25 legs of lamb roasted by method 4. The data for this comparison of grades indicate no significant difference in evaporation loss of Choice, Good, Medium, and Common grade lamb. Here again Cull grade lamb differed from the other grades, but this time it lost less than they did by evaporation.

The rate of heat penetration was influenced by the carcass grade where each grade was reasonably well represented. According to the data in table 3 there was no significant difference in the number of minutes per pound required to roast Choice, Good, and Medium grade lamb by method 1, but Common and Cull grade lamb took longer to cook in proportion to the weight. The same result is suggested by the data on 25 legs roasted by method 4. In the other grade comparisons in tables 3 and 4 results are not considered significant because of the small number of samples.

Since the same method of cooking was used in each group of carcass grade comparisons shown in tables 3 and 4, and since the ripening periods were kept much the same on the average, the causes of variation in shrinkage and cooking time associated with carcass grade are not to be sought in cooking method or in ripening. According to Weber and his associates (7) the fatness of lamb determines the fat loss on cooking. Of course the legs that were cooked could not be analyzed for fat content. The corresponding uncooked legs were not analyzed either. However, there was recorded at the time of cooking a visual estimate of the relative fatness of each leg of lamb and mutton. These judgments of "finish" were made by the writers, following the system started in 1927 by D. A. Spencer of the Animal Husbandry Division of the Bureau of Animal Industry. On the basis of appearance the legs of lamb ranged in fatness from an extremely large amount to none visible and were graded in five classes. When the finish grades of the legs were compared with the official grades for the carcasses for 924 lambs, a sample which included many of those discussed here, the coefficient of linear correlation was $+0.78 \pm 0.009$, indicating that the visible fat on the leg was closely related to the carcass grade of lamb.

Data on the fat and water content of a small number of lamb legs from Choice, Good, Medium, Common, and Cull grade carcasses have been contributed by the Animal Husbandry Division of the Bureau of Animal Industry and are summarized in table 5.

TABLE 5.—*Water and fat content of lamb legs of Choice, Good, Medium, Common, and Cull grades determined by chemical analysis and expressed as percent of weight as purchased*

Carcass grade	Samples	Water content		Fat content	
		Average	Range	Average	Range
	Number	*Percent*	*Percent*	*Percent*	*Percent*
Choice	7	51.8	48.6–54.8	18.2	15.2–21.4
Good	9	53.7	49.8–57.5	14.7	11.6–17.5
Medium	7	54.4	49.2–58.5	11.6	10.2–13.4
Common	2	53.9	52.9–54.9	8.2	8.1– 8.4
Cull	5	55.2	52.0–58.1	4.7	1.4– 7.4

According to these data the fat content of leg of lamb as purchased varies directly with the carcass grade. The higher the grade the more fat there is in the leg. The water content of leg of lamb as purchased varies less consistently with carcass grade, but from these data appears to be greater for Cull lamb than for Choice.

On comparing drippings and evaporation loss of leg of lamb of the different carcass grades as shown in table 3 respectively with the fat and water content as shown in table 5, it appears that composition determines what the character and relative amount of the shrinkage will be, other things such as ripening and cooking method being equal.

The range in water and fat content of lamb leg in table 5 indicates considerable variation within grades, consequently it is to be expected that shrinkage also will vary within grades. A good deal of variation existed in each grade as shown by the standard error of the means of the large samples (table 3). Averages based on a small number of samples therefore cannot be expected to be the same as if a large number had been used.

It is unsatisfactory to attempt to explain the rate of heat penetration by the chemical composition of meat. The weight of a leg of lamb as well as the fat and water content undoubtedly influences the number of minutes per pound required to cook it. There appears to be a considerable range in fat content and in weight over which these factors do not influence the rate of heat penetration, as for example in Choice, Good, and Medium grades. However, with a sharp decrease in fat content and in weight, such as found in either Common or Cull lamb, the speed of cooking declines.

As far as it is possible to make comparisons, the results are in general accord with those reported by Weber, Loeffel, and Peters (7).

SHRINKAGE AND RATE OF HEAT PENETRATION AS INFLUENCED BY THE METHOD OF COOKING

Seven methods of roasting lamb and mutton were employed, including five different oven temperatures and two meat temperatures, or stages of doneness. These methods have already been described (p. 4). In comparative tests methods 2 to 7 were always checked against method 1, since it is the one by which the largest number of samples were cooked. Wherever possible, both legs from the same carcass were used, the leg from one side cooked in one way and the corresponding leg in another on the same day. This arrangement keeps the composition of the meat essentially the same for each comparison of two methods of cooking and so reduces the number of variables in an experiment.

OVEN-TEMPERATURE VARIATIONS

As already stated, for method 1 lamb or mutton was seared for 20 minutes at an average oven temperature of 265° C., then the cooking continued very slowly at 125° until the thermometer inserted in the meat registered 76°. From the 749 legs of lamb roasted by this method and summarized in table 3, the 18 Cull grade legs were omitted as not representative of the lamb ordinarily found on the market. This leaves 731 of Choice through Common grade, ripened for an average of 10 days. Shrinkage data and cooking time were averaged for these 731 samples and are presented graphically in figures 1 and 2,

group *A*. Data for three other groups of legs of lamb cooked by this method are also shown in figures 1 and 2, *B*, *C*, and *D*. These groups contain, respectively, 20, 8, and 21 legs of lamb, in part the mates of samples reported in table 3. Table 6 contains data on another group

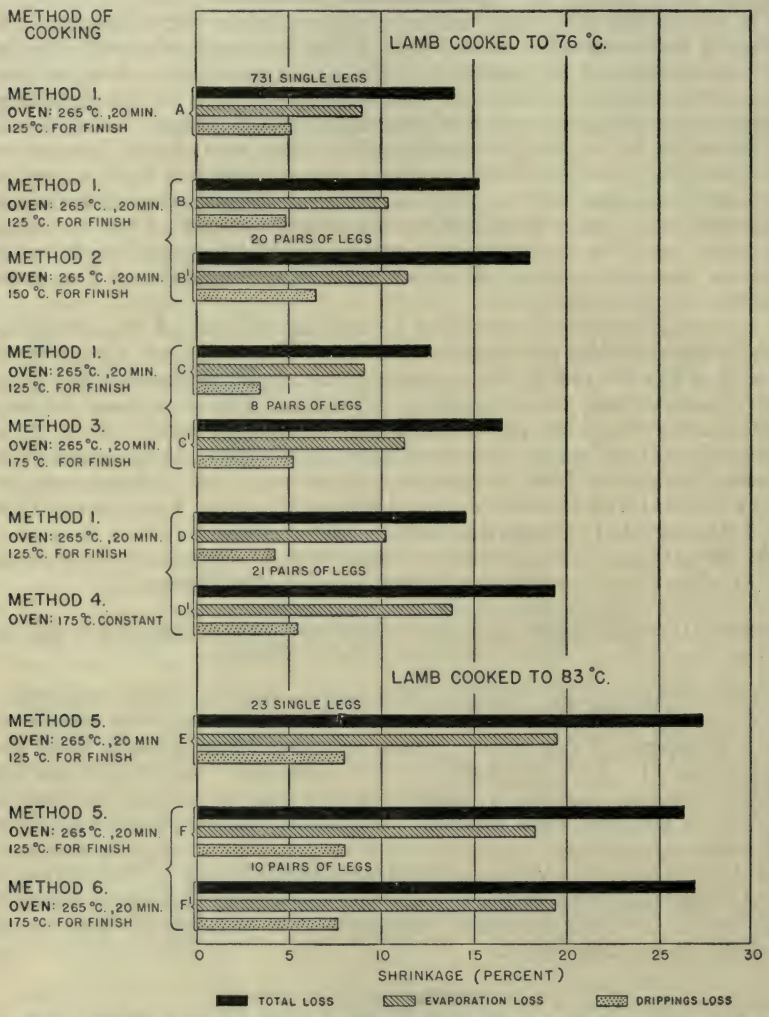

FIGURE 1.—Average shrinkage of several lots of lamb legs during roasting as affected by variations in oven temperature and in cooking to different stages of doneness. The losses are expressed as percent of the weight of the uncooked cut.

of legs of lamb cooked by method 1. Since the pairs of legs were cooked to compare different oven temperatures they are discussed in detail below.

Nine left legs of mutton were cooked by method 1 as reported in table 4. The ripening period ranged from 4 to 9 days, averaging 6. When the figures for shrinkage and cooking time were averaged the following results were obtained: Evaporation loss, 11.7 percent;

drippings loss, 3.8 percent; total loss, 15.4 percent; minutes per pound, 30.6.

Method 2 employs the same searing and the same meat temperature as method 1, but for the oven temperature uses 150° C. for the finish. The two methods were compared on pairs of legs of lamb and mutton to show the effect on shrinkage and cooking time when the finishing oven temperature was raised from 125° to 150°. Twenty pairs of legs of lamb and four pairs of legs of mutton were cooked by these two methods. Four pairs of the lamb legs came from graded carcasses (table 3). The remaining 16 pairs were from ungraded carcasses,

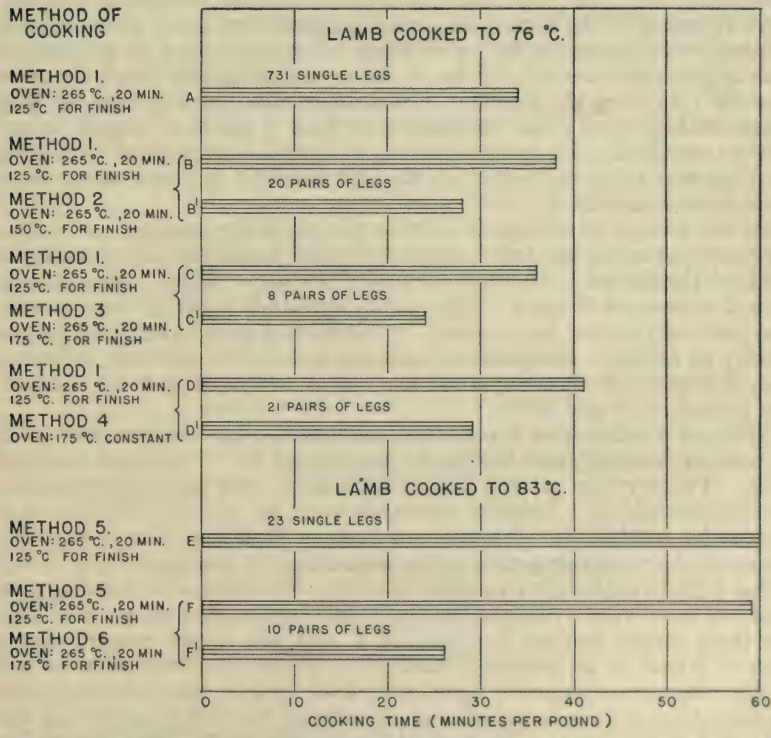

FIGURE 2.—Average time required for heat to penetrate lamb legs roasted by various methods and to various degrees of doneness. The cooking time is expressed as minutes per pound of the uncooked cut.

but finish grades assigned in the cooking laboratory indicated that all were of a moderate to a very high degree of fatness, except 1 pair which probably would have been graded Common. The ripening period ranged from 4 to 9 days, and averaged 7. Shrinkage and cooking time of the 20 pairs of legs were averaged for the two methods of cooking and are shown graphically in figures 1 and 2, as groups *B* and *B'*.

Of the four pairs of mutton legs, the left legs cooked by method 1 are reported with five others in the first section of table 4, and their mates cooked by method 2 appear in the second section of the table. The ripening period ranged from 4 to 5 days. Following are the averages, respectively, for the four pairs of legs of mutton cooked by

methods 1 and 2: Evaporation loss, 13.4 and 16.1 percent; drippings loss, 3.6 and 4.1 percent; total loss, 16.9 and 20.3 percent; minutes per pound, 32.8 and 26.8.

According to method 3 lamb and mutton were seared the same as in method 1 and cooked to the same stage, 76° C., but the finishing oven temperature was 175° instead of 125°. Eleven pairs of lamb legs and five pairs of mutton legs were cooked by these two methods to show the effect on shrinkage and cooking time of raising the oven temperature from 125° to 175° for the finish after searing. Table 3 reports data on the 11 legs of lamb cooked by method 3. Omitting the 3 pairs of Cull grade samples, the remaining 8 pairs averaged 8 days ripening. Shrinkage and cooking time for the 8 pairs cooked, respectively, by methods 1 and 3 are shown graphically in figures 1 and 2, groups *C* and *C'*. The 3 pairs of Cull grade lamb legs were ripened 7 days on the average. Shrinkage and cooking time for these 3 pairs of Cull grade legs cooked by methods 1 and 3 averaged, respectively, as follows: Evaporation loss, 11.3 and 11.8 percent; drippings loss, 0.7 and 1.3 percent; total loss, 12.0 and 13.1 percent; minutes per pound, 49.4 and 26.4.

Of the five pairs of legs of mutton the right legs cooked by method 3 were reported in the third section of table 4, and the lefts cooked by method 1 included in the first section of the same table. The ripening period averaged 7 days. The shrinkage and cooking time for the five pairs of mutton legs cooked by methods 1 and 3 averaged, respectively, as follows: Evaporation loss, 10.4 and 15.2 percent; drippings loss, 3.9 and 4.6 percent; total loss, 14.3 and 19.8 percent; minutes per pound, 28.9 and 19.5.

Method 4 employed a constant moderate oven temperature, 175° C. without searing, and the lamb was cooked to 76° internal temperature. Twenty-five pairs of legs of lamb were used to compare method 4 with method 1. Table 3 contains data on the 25 legs that were cooked by method 4. When the 4 pairs of Cull grade lamb legs were omitted, the ripening period of the remaining 21 pairs averaged 8 days so far as information is available (p. 12). The data for shrinkage and cooking time were averaged for the 21 left legs cooked by method 1 and for their mates cooked by method 4 and are shown graphically in figures 1 and 2, as groups *D* and *D'*. When the four pairs of Cull grade lamb legs, ripened 8 days, were averaged to show shrinkage and cooking time for the two methods of roasting, the following results were obtained, respectively, for method 1 and method 4: Evaporation loss, 10.6 and 9.3 percent; drippings loss, 1.8 and 2.0 percent; total loss, 12.4 and 11.3 percent; minutes per pound, 43.4 and 34.4.

Prior to the adoption of the standard laboratory method for palatability tests lamb was cooked well done to 83° C. (method 5). By this method the legs were seared either for 35 minutes at 250° or for 20 minutes at 265°. Since the two searing methods did not appear to affect the shrinkage differently, no distinction is made here. After searing, the finishing oven temperature was 125°. Twenty-three single legs of lamb were cooked by this method. Eleven legs were from carcasses graded Choice, Good, Medium, and Common. The remaining 12 were not graded. The ripening period for 21 of the 23 legs ranged from 3 to 10 days, averaging 7. The shrinkage and cooking time were averaged for the 23 legs, and the results are shown

graphically in figures 1 and 2, as group *E*. The 10 single legs of lamb cooked by method 5, for which shrinkage and cooking time are shown graphically in figures 1 and 2, group *F*, are included in the group of 23 and are discussed in detail below.

According to method 6 lamb was seared the same as by method 5 and cooked to the same stage, 83° C., but the finishing oven temperature was 175°. Ten pairs of legs of lamb were roasted by methods 5 and 6 to show the effect on shrinkage and on cooking time caused by raising the oven temperature for the finish from 125° to 175° for well-done lamb. Eight pairs were from carcasses graded Choice and Good (table 3) and were ripened for an average of 8 days. The remaining two pairs were from ungraded carcasses of unknown ripening period. The data for shrinkage and cooking time of the 10 pairs were averaged for the two methods of cooking and are shown graphically in figures 1 and 2, as groups *F* and *F'*.

According to method 7 lamb was cooked the same as in method 1 except that it was not seared. Ten pairs of legs of lamb were roasted by methods 1 and 7 to show the effect of searing on shrinkage and cooking time. Eight pairs were from Good grade carcasses and ripened for an average of 8 days. The remaining two pairs were from carcasses graded Medium, but since they were purchased at a market their ripening period was not known. The data for shrinkage and cooking time of the 10 pairs were averaged for the two methods of cooking and are shown in table 6.

TABLE 6.—*Effect of searing on shrinkage and cooking time of paired lamb legs when roasted to 76° C. internal temperature*

Roasting method and oven temperature	Number and description of samples	Weight of uncooked leg	Shrinkage during roasting			Cooking time per pound
			Evaporation	Drippings	Total	
		Grams	*Percent*	*Percent*	*Percent*	*Minutes*
Method 1: 265° C. for searing; 125° for finishing.	10, left	2,058	10.8	4.9	15.7	39.3
Method 7: 125° C. entire time	10, right	2,091	8.4	3.4	11.8	44.7
Difference		−33	+2.4	+1.5	+3.9	−5.4
Standard error of the difference		±18.0	±.44	±.27	±.63	±1.77

Before discussing the effect of varying the oven temperature, attention is called to the data for the four groups of lamb legs in figures 1 and 2, designated as *A*, *B*, *C*, and *D*, and the seared group in table 6. Although all were cooked by method 1, they show discrepancies in shrinkage and also in cooking time as minutes per pound. If the groups *B* and *D* and the seared group in table 6 had been ripened 10 days on the average instead of 7 or 8, it is believed that the shrinkage and cooking time would have been nearer to the values shown for group *A*. The shrinkage of group *C* was unaccountably low for lamb ripened 8 days.

To show the effect of varying the oven temperature on the shrinkage and cooking time of lamb and mutton, the means of the paired samples in groups *B* and *B'*, *C* and *C'*, *D* and *D'*, and *F* and *F'*, also for the two groups each of Cull grade lamb and of mutton of several

grades, and for the seared and unseared groups in table 6, were tested for significant differences as described on page 7. In addition, the differences between means were further checked by comparing them with allowances for experimental error (p. 8).

Results showed that for lamb and mutton of Choice through Common grade when cooked to an internal temperature of 76° C., the higher oven temperatures employed in methods 2 and 3 caused greater shrinkage than method 1 and cooked the meat more quickly.

On comparing method 4 with method 1 (groups *D* and *D'*), lamb of Choice through Common grade roasted at a constant moderate oven temperature, 175° C., shrank more than when it was first seared at 265° and then finished at 125°. This finding is significant. The data in table 6 show that searing itself not only does not decrease the shrinkage of roasts as was once thought, but actually increases it, with the drippings loss increased proportionately more than the evaporation loss. In the case of method 1 and method 4, however, a method that included searing caused less shrinkage than a constant temperature roasting method. The data in groups *D* and *D'* suggest that method 4 gave higher average temperature than method 1. From these results it appears that in roasting meat shrinkage is affected more by average oven temperature than by initial searing.

Cull grade lamb again proved different from the higher grades, this time in response to variations in oven temperature during roasting. Whereas Choice, Good, Medium, and Common grade lamb when cooked to 76° C. internal temperature shrank more as the oven temperature was raised from 125° to 175°, Cull lamb treated similarly did not shrink significantly more at the higher temperatures. It appears that the time in the oven had some effect on the shrinkage, since Cull lamb took proportionately much longer to cook at 125° than at higher oven temperatures.

For lamb of Choice and Good grades cooked to 83° C., raising the oven temperature from 125° to 175° for the finish after searing did not increase the shrinkage significantly according to the comparison of methods 5 and 6 in groups *F* and *F'*, figure 1. This is a different result from the comparison of methods 1 and 3, although in the two experiments the same oven temperatures were contrasted. The finding with respect to lamb cooked to 83° is significant because it is contrary to the general belief that a low oven temperature always holds down the shrinkage of meat. That the long time required to cook lamb well done in a very slow oven decidedly affected the shrinkage is clear from the data in groups *F* and *F'*, figure 2.

MEAT TEMPERATURE VARIATIONS

Method 5 and method 1 differ only in the stage to which lamb is cooked, respectively 83° and 76° C. Although there were no pairs of legs of lamb cooked by these two methods there were several groups containing unrelated samples, namely, groups *A*, *B*, *C*, or *D* for method 1 and *E* or *F* for method 5.

Similarly the shrinkage and cooking time of group *C'* cooked by method 3 can be compared with those of the unrelated group *F'* cooked by method 6, figures 1 and 2. These two methods also differ only in the stage to which lamb is cooked, respectively 83° C. for method 6 and 76° for method 3.

Statistical treatment is not necessary to show the obvious effects on shrinkage and cooking time brought about by varying the stage of doneness or internal meat temperature. For the two groups *C′* and *F′*, however, the cooking time was compared by Fisher's method (*2, pp. 114–118*). The difference between the means was further checked by comparison with allowances made for experimental error (p. 8).

According to the results, lamb roasted well done, 83° C., shrank much more than lamb roasted only to the medium-to-well-done stage, 76°. The increase in the shrinkage associated with raising the meat temperature from 76° to 83° was almost 100 percent when the low oven temperature of 125° was used for finishing after searing, as in methods 1 and 5. Figure 2 shows that the cooking time was also greatly increased; in fact in many individual cases it was doubled. These groups, as already noted, were made up of unpaired legs of lamb, so they differed in composition, hence the difference in shrinkage and cooking time cannot be ascribed entirely to method of cooking. In addition there were some cases where the grade composition was not known. This probable dissimilarity makes it impossible to estimate how much of the difference might be attributed to grade, but it is believed to be relatively small.

Similarly, an allowance should be made for the effect of the composition of the meat on the shrinkage and cooking time for lamb cooked to 83° C. and only to 76° when the oven temperature was moderate, or 175°, for the finish after searing, as in methods 6 and 3. In this case the data for lamb cooked to 83° showed a 60 percent increased shrinkage over lamb cooked to 76°. With the higher oven temperatures used in methods 6 and 3, little longer time is required to raise the meat temperature from 76° to 83°. In groups *C′* and *F′* of figure 2, the difference between the means is insignificant, but since the groups were small and the legs were not paired, the results are not conclusive for cooking time.

RESULTS OF EXPERIMENTS ON COOKING METHOD

Summing up these experiments on the effect of method of cooking on the shrinkage of lamb and mutton, the results show that the oven temperature, the stage of doneness, and the length of time required to bring the meat to any particular stage of doneness all combined to influence the shrinkage during roasting. The lower the oven temperature, the longer was the time required to cook the meat to a particular stage of doneness, as would be expected. The more thoroughly the meat was cooked, the longer was the time required, as would also be expected. Low oven temperatures held down shrinkage except when the time required was excessively long in proportion to the weight of the roast. The lower the oven temperature the less was the shrinkage of lamb cooked medium to well done, 76° C., except for the small lean legs of Cull grade lamb. They required proportionately much longer time to cook in a very slow oven (125° after searing) than in a moderate oven (175° after searing) and showed no significant difference in shrinkage. Also for lamb cooked well done (83°) shrinkage was not significantly different at these same oven temperatures because 1 hour per pound was required when 125° was used as the finish after searing, whereas only half as long was needed when seared roasts were finished at 175°.

ESTIMATING SHRINKAGE AND COOKING TIME OF LAMB AND MUTTON ON THE BASIS OF EXPERIMENTAL RESULTS

Of special interest to meat producers and to those consumers who are looking for pointers on selection is the shrinkage expected of the different grades of lamb. According to information from the Division of Livestock, Meats, and Wool of the Bureau of Agricultural Economics, the bulk of the market supply of lamb reaches the consumer 7 to 10 days after slaughter and consists of Choice, Good, and Medium grades with the greatest number falling in the lower third of the Good grade.

The data in table 3 indicate that for 168 legs of Choice grade lamb ripened for an average of 9 days, prepared for roasting with the fell on and without seasoning, and roasted by method 1, in 95 percent of trials the average total loss of weight would fall between 15 and 16 percent. Similarly for 389 Good grade lamb legs ripened for an average of 10 days, the total loss of weight would be about 14 percent, and for 142 legs of Medium grade lamb aged 11 days on the average, from 12 to 13 percent. It is roughly estimated for lamb of Common and Cull grades when ripened for an average of 10 days and cooked by method 1 that the total loss of weight will fall between 11 and 12 percent.

The time required to cook Choice, Good, and Medium grade lamb legs by method 1 is estimated to average 34 to 35 minutes per pound, but varies considerably for individual legs. It is exceedingly difficult to predict cooking time for low-grade lamb when this method of cooking is used, but 40 to 45 minutes per pound is reasonable.

There were so few legs of lamb in each of the several carcass grades when other methods of cooking were used, as appears in table 3, that estimates by grades are not attempted.

Having shown that ripening has a definite effect on shrinkage and cooking time, the writers offer here estimates of shrinkage and cooking time based on averages of five groups of legs of lamb cooked by method 1 at different periods of ripening. The ripening periods averaged 4, 8, 10, 11, and 17 days, respectively, for 60 samples (table 2), 51 (from groups *B*, *C*, and *D*, figs. 1 and 2 and the seared group in table 6), 731 (table 3 and group *A*, figs. 1 and 2), 93 (table 1), and 60 (table 2). From the data it is estimated that for 60 legs of lamb including 29 Choice grade, 26 Good, 3 Medium, and 2 Common, ripened 4 days and cooked by method 1, shrinkage may be expected in 95 percent of trials to vary from 15 to 16 percent. Similarly for 51 legs of lamb ranging in grade from Choice to Common, averaging between Good and Medium and ripened 8 days, the shrinkage is estimated at 14 to 15 percent; for 731 legs of lamb ranging in grade from Choice to Common (table 3), averaging Good grade, and ripened for an average of 10 days, at 14 percent; for 93 legs of lamb made up of 21 of Choice, 50 of Good, 21 of Medium, and 1 of Common grade, ripened for an average of 11 days, at 13 percent; and for 60 legs of lamb mainly Choice to Good, as already noted, ripened for an average of 17 days, at 13 percent.

Cooking time as minutes per pound is estimated for groups of the composition of the above, respectively at 38 to 39, 37 to 39, 34 to 35, 31 to 32, and 35 to 37. The estimates for lamb ripened 11 and 17 days are not believed to be typical. However, they serve well to call attention to the fact that although longer ripening makes lamb cook

faster, there are other factors involved also, and it is not possible to make close estimates for individual legs on the basis of a certain number of days of ripening. In fact, so far no satisfactory basis has been found for close estimates of cooking time for individual legs of lamb roasted by method 1. Because this is so, method 1 is difficult even for the laboratory and is not recommended for household use. However, since it is the method by which the largest number of samples has been cooked, it is the basis for estimating the shrinkage and cooking time for the other methods. With the exception of methods 5 and 7, the others are held to be more practical.

For the general market supply of leg of lamb roasted by methods 2, 3, 4, 5, 6, and 7, estimates of shrinkage and cooking time are very rough because they are based on small samples, respectively groups B', C', D', E' and F' in figures 1 and 2 and the unseared group in table 6. When method 2 is used, the shrinkage is predicted to range between 15 and 18 percent and the cooking time from 25 to 27 minutes per pound on the average.

For leg of lamb roasted by method 3 shrinkage is estimated at 17 to 20 percent and cooking time at 23 to 24 minutes per pound. However, since the shrinkage figures are based on only eight pairs which showed rather low cooking losses, they are believed to be smaller than should occur in the long run. The estimated cooking time, on the other hand, is believed to be too high.

For lamb roasted by method 4 shrinkage is estimated at 17 to 20 percent and cooking time at 24 to 26 minutes per pound on the average. Incidentally, as between methods 3 and 4, if meat of the same composition were used, the searing in method 3 would be expected to increase shrinkage 3 to 5 percent, and to decrease the cooking time about 5 minutes per pound.

For leg of lamb cooked well done, 83° C., by methods 5 and 6, shrinkage is estimated at 25 to 30 percent, whether the finishing temperature after searing is 125° or 175°. Cooking time is estimated at 1 hour per pound for method 5 and half an hour per pound for method 6.

For leg of lamb roasted by method 7 shrinkage is estimated at 10 to 11 percent and cooking time at 39 to 41 minutes per pound.

The number of mutton samples was too small to provide a reliable basis for predicting shrinkage and cooking time, but as far as can be judged from the data leg of mutton will shrink somewhat more than leg of lamb of the same grade and cook more quickly in proportion to its weight. This is contrary to a general belief that larger pieces of meat shrink proportionately less than do small ones, but is in accord with the belief that very large cuts cook faster in proportion to their weight.

SUMMARY AND CONCLUSIONS

The influence of carcass grade, period of ripening, and method of cooking on the shrinkage (loss of weight) and rate of heat penetration during roasting was determined in a series of experiments on 1,185 legs of lamb and mutton, including Choice, Good, Medium, Common, and Cull grades, ripening periods of from 2 to 24 days after slaughter, and seven different cooking methods. Studies on cooking method included variations in oven temperature and varia-

tions in the stage of doneness to which lamb was cooked as determined by a roast-meat thermometer. Oven temperature was raised from 125° C. to 175° for the finish after 20 minutes searing at 265°, and the effects on shrinkage and cooking time compared, and constant-temperature roasting at 125° and at 175° was compared with the sear at 265° plus finish at 125°. Also the lamb was cooked to two stages: 76°, medium to well done, and 83°, well done.

A preliminary study was made to determine what is a significant difference in shrinkage and cooking-time data for averages of 10, 20, and 93 legs of lamb roasted by the standard laboratory method used for palatability tests in the cooperative meat investigations.

The higher the grade of lamb and mutton the greater was the shrinkage, due mainly to the rendering out of more fat into the drippings from the better finished high-grade meat. Since pan drippings are usually made into gravies and sauces they do not necessarily represent a loss of nutritive value. Although drippings sometimes contain more fat than can be used, this excess fat should not be looked upon as cooking waste because it probably would not have been eaten even if it had been retained by the roast. Whereas drippings loss decreased with grade, the water lost by evaporation during roasting did not follow grade consistently. Choice, Good, and Medium legs of lamb cooked more rapidly in proportion to their weight than lamb of Common and Cull grades.

Increasing the length of the ripening period after slaughter decreased the cooking shrinkage and shortened the time required to roast leg of lamb. As the ripening period of lamb increased beyond 2 days after slaughter, the cooking shrinkage became smaller and the rate of heat penetration more rapid. The decrease in loss of weight in the oven is of special interest because it offsets to some extent the loss of weight in the cooler during storage. No studies were made on fuel consumption in relation to ripening, but of course with faster heat penetration there would be less fuel required per pound of meat cooked.

Among the studies on oven-temperature variations as influencing shrinkage, the comparisons of the constant low and constant moderate temperature methods with a method that includes an initial sear and a slow finish are of special interest. The average oven temperature for the combination of 265° C. for 20 minutes searing and 125° for finishing was higher than 125°, the constant low temperature used. There was a difference of 4 percent in the shrinkage of lamb legs roasted by these two methods and the smaller loss was associated with the lower average cooking temperature. That is to say, the unseared legs shrank less. In contrast, the average oven temperature for the combination of 265° for 20 minutes searing and 125° for finishing was lower than 175°, the constant moderate temperature used. Again there was a difference of 4 percent in the shrinkage of lamb legs roasted by the two methods, and the smaller loss was associated with the lower average cooking temperature, which however in this case included an initial sear. This time the unseared legs shrank more. This goes to show that searing in itself does not reduce shrinkage, as was once thought, but actually makes a roast lose more weight, though the extra loss is mainly fat. The significance of these results lies in the fact that it is the average oven tem-

perature which has more influence on shrinkage than does the initial sear.

As a whole the studies show that the lower the oven temperature the smaller was the shrinkage of leg of lamb cooked to the medium-to-well-done stage (76° C.). At the lowest oven temperature used, constant 125°, the shrinkage averaged 12 percent and the cooking time 45 minutes per pound. When lamb legs were first seared, and then finished at different oven temperatures, at the lowest finishing temperature, 125°, the meat shrank 13 percent, while at the highest, 175°, the shrinkage averaged 17 percent. The cooking time ranged from an average of 36 to an average of 24 minutes per pound, respectively.

In contrast when leg of lamb was cooked well done (83° C.) by these same oven temperatures, 125° and 175° following searing, the shrinkage was not significantly different, averaging 27 percent. The cooking time averaged 60 minutes per pound by the former method and 25 by the latter. Without doubt the time influenced the shrinkage.

These tests on the influence of cooking method showed that the stage to which leg of lamb was cooked made more difference on the shrinkage than the oven temperature that was chosen. The results bring out an important point in meat cookery with respect to controlling shrinkage: The stage of doneness to which meat is cooked in roasting may make more difference on the shrinkage than the specific oven temperature used. This is a good argument for the use of a roast-meat thermometer in addition to an oven thermometer because the meat thermometer shows when the desired stage of doneness is reached and prevents overcooking and excessive shrinkage.

On the basis of experimental data estimates of shrinkage and cooking time were worked out to apply to lamb and mutton as the consumer is likely to find it on the market, when cooked by the methods described in this bulletin.

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The data reported in this bulletin were obtained from experiments conducted by the Bureaus of Animal Industry, Agricultural Economics, and Home Economics of the United States Department of Agriculture and agricultural experiment stations of the following States: Indiana, Maryland, Mississippi, New Mexico, New York, Tennessee, and West Virginia.

Responsibility for the various phases of the work was as follows:

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POLICIES GOVERNING THE OWNERSHIP OF RETURN WATERS FROM IRRIGATION

By

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POLICIES GOVERNING THE OWNERSHIP OF RETURN WATERS FROM IRRIGATION

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INTRODUCTION

The ownership of return flow of irrigation water is a matter which has concerned State administrative officials in increasing degree in recent years. It has been much debated at their annual conventions. Return waters from irrigation constitute a large percentage of the total water supply available for further use from many important stream systems; yet the courts have ruled on the question of ownership in only a few States, and only in one State (Colorado) have the decisions been sufficiently numerous to furnish comprehensive precedents for its varying angles. The present inquiry has been undertaken for the purpose of securing information upon the extent of use of return flow for irrigation purposes, the nature of conflicts over the right to its use, its effect upon irrigation development gen-

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erally, the character and operation of policies governing its control and reuse, and the necessity, if any, for further formulation or modification of policy.

The study was made in 13 of the Western States—the 11 States farthest west, and Nebraska and Texas—by personal visits to important localities and by consultation with the several State administrative authorities.

DEFINITION OF RETURN FLOW

Return flow from irrigation may be defined as that portion of water diverted for purposes of irrigation which eventually finds its way back to the stream from which diverted, or to some other stream, or which would find its way back if not intercepted by some natural or artificial obstacle.

Return flow includes both avoidable and unavoidable losses from the project. Part of the return is water which has escaped from control by means of leakage through and around structures, seepage through canal banks, and penetration below the root zones of plants; and part is water purposely released from the ends of canals and over wasteways.

Return water normally returns to the stream from which diverted. However, if transported to another watershed, in which case it would naturally drain toward a different channel, such water would nevertheless still be properly classed as return water. It is foreign to the stream toward which it now drains, but is nevertheless return water from irrigation. Return flow on its way back to the stream may be intercepted by a subterranean dike; or may be collected in drainage ditches or pumped from underground and reused for irrigation before reaching the stream, without losing its character as return flow.

Visible return flow is that portion of the return water which appears at the surface of the ground before reaching the stream. It collects and is returned to the stream in artificial or natural drains, or appears in small rivulets or waterfalls, and therefore is often directly measurable.

Invisible return flow is that portion which seeps into the river channel through the banks, below the surface of the stream, or which rises through the bottom. Obviously it is seldom directly measurable. For a given stream section, the nearest quantitative approximation that can be made of invisible return flow is a calculation of invisible net gain (or, it may be, net loss) within the section, made by deducting the sum of all measured inflows from the sum of all measured outflows.[1]

However, all accretions to a stream within an irrigated region, even where no surface importations are evident, may not be return water from irrigation. The problem of measuring the quantity of return is often complicated by additions to the underground supply caused by seepage into the basin from surrounding elevations

[1] Formula, $x=(b+d)-(a+c)$,
Where a=flow of stream at upper end of section
b=flow of stream at lower end of section
c=visible return flow to section
d=diversions from section
x=invisible net gain or, if a minus quantity, net loss.

and by rainfall within the basin. Likewise, excessive return flow shown by measurements taken during the falling stages of streams has been attributed partly to the release of water stored in adjacent sands during the rising stages (*11, pp. 96–98; 22, p. 48*).[2]

Western streams commonly lose water by seepage and evaporation after leaving the mountains in which they rise. Return flow from irrigation partly offsets this loss in certain localities and completely overcomes it with resulting net gains in others.

THE PHENOMENON OF RETURN FLOW

EARLY RECOGNITION

The earliest observations in the United States, so far as the author is aware, of the relation between seepage from irrigated lands and increases in river flow below the lands were in Colorado. The second State engineer of Colorado (E. S. Nettleton), writing in 1884, commented upon the increase in the autumn discharge of streams in the irrigated area during the preceding 14 years, notwithstanding his reasonable certainty that the rainfall had not increased; and spoke of the subsidence of alarm on the part of residents of lower Cache la Poudre Valley and elsewhere over the scarcity of water, in the face of their declarations 8 years earlier that no new diversions should be made, and in spite of the fact that new appropriations of water had been made in each succeeding year (*18, Rept. 2, pp. 17, 34*). Two years later Nettleton reported the results of a series of measurements to obtain accurate information concerning seepage water in the Cache la Poudre (*18, Rept. 3, pp. 210–214*). It appears that the increase in flow of water in the lower valley of the South Platte had been attracting attention and had led to the construction of new canals for the purpose of taking advantage of it. Seepage studies on the Poudre and South Platte were made in succeeding years by Carpenter and others (*3*), and were continued on the South Platte with considerable regularity by incumbents of the State engineer's office. Parshall (*22*) in 1922 published a comprehensive study on seepage return to the lower South Platte.

In the meantime the phenomenon had been observed and studied elsewhere in the West.[3] Without attempting to list all the references, it may be stated that Fortier (*8*) investigated the matter in Ogden Valley, Utah, in 1894 and concluded that the use of water in the upper valley increased the available supply to certain lower areas during the greater part of the irrigating period. Dr. Fortier reported further studies made in Utah in 1896 (*9, 10*), and in Bitter Root Valley, Mont., in 1903 (*11, pp. 84–93*). In Arizona, on the Gila River, measurements made in 1899 were reported by Newell (*19, pp. 340–347*), and on the Salt River the relation between irrigation and return water was discussed by Code (*4, pp. 103–105*) in 1900. Measurements on the North Platte in Wyoming and Nebraska were made in 1903 in connection with a study of water rights on certain interstate streams (*25, pp. 48–50*). In more recent years the results of many studies of return flow have been published in several of the Western States, principally by State engineer offices.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 47.

[3] Carpenter, writing in 1896, also cites instances in India, Italy, and France (*3, pp. 58–60*).

Some of the early works on seepage inflow to streams laid little or no stress upon the fact that all accretions were not necessarily due to return water from irrigated land; while others pointed out carefully the various possible sources of gain.

In the following pages will be found (1), a description of conditions on a number of typical streams with reference to return flow; (2) a discussion of controversial questions which have arisen in connection with the appropriation of return waters and opinions of the courts bearing on these questions; (3) an impartial statement of both sides of the controversy over public versus private ownership of return water; and (4) an analysis of the principles upon which an equitable policy can be formulated. The chief purpose of the publication is to set forth clearly a statement of the equitable principles governing the use of return waters as an aid in the efficient utilization of the streams in the arid and semiarid regions.

RETURN FLOW ON IMPORTANT STREAM SYSTEMS

Recognition of the existence of return water from irrigation is now widespread throughout the West. Accretions from this source are to be noted along the portions of practically all streams within irrigated valleys, except in those comparatively rare formations (for example, the Lower Rio Grande Delta in Texas-Mexico) in which the return from irrigation drains away from the stream channel rather than into it, and except in other cases in which the irrigation water is applied beyond the height of land along the watercourse.

The following brief statements are designed to emphasize the widespread existence of this important feature of western stream flow and to point out the various ways in which it has become manifest and the resulting complications in irrigation water rights and development.

YAKIMA RIVER, WASH.

The irrigable land of Yakima Basin, Wash., lies in three main areas—Kittitas Valley, which ends a short distance below Thrall, after which the river flows through precipitous country; the Yakima area, with a pronounced constriction at Union Gap; and the extensive area between Union Gap and the mouth of the river at Richland. The Yakima thus lends itself readily to the functioning of return flow, and the fact has been recognized for many years.[4] The amount of return in each of these areas is considerable, but complete return-flow studies in the basin have not been made.

In the area below Union Gap the quantity of return flow from the Wapato and Sunnyside projects has been such that in a season of water shortage it has been possible to dry the river at the Sunnyside diversion and still supply the lower projects.

The river is regulated by officials of the Yakima project of the Bureau of Reclamation. The Bureau has constructed extensive storage and distribution works and has agreements with holders of

[4] Records compiled by a local engineer in 1905 showed that 11 percent of the water diverted in Yakima Basin during that year was taken out while the total diversions exceeded the combined flow of supply streams.

old rights under which storage water is furnished to supplement direct flow.

An important feature of the return-water situation is illustrated by the recovery and reuse of drainage waters on Wapato project of the United States Indian Irrigation Service. The topography is favorable, and the soil "is disintegrated basalt underlaid with gravel susceptible of excellent drainage".[5] Several of the main laterals are paralleled by drainage ditches. The method of diversion is to check up the drain and raise the water level to a point where it can be taken out into an irrigation ditch. In 1930 nearly a fourth of the 82,472 acres irrigated on the project were supplied in this way. A pumping unit of 8,700 acres has since been installed for the utilization of drainage waters as well as natural flow. A subdivision of the Satus unit consisting of 8,800 acres is supplied by gravity from the main Wapato drain, 3,215 acres having been irrigated thus in 1931; and another with 2,929 acres irrigated that year pumps drainage water as the principal part of its supply. More than one-third of the drainage yield of the project was recovered and reused for irrigation in 1930 before reaching the river. When all of the lands served by these additional units are in cultivation, it is anticipated that the net drainage return to the river will be substantially lowered.

UMATILLA RIVER, OREG.

Most of the land irrigated from the Umatilla River in Oregon lies along its lower reaches below Echo and along the Columbia below the junction of the Umatilla and Columbia. The Umatilla project of the Bureau of Reclamation covers by far the larger part of the irrigable land. The project is covered by two irrigation districts—Hermiston and West Extension. A large amount of seepage water arises on Hermiston district. The soil is sandy and is underlaid with gravel; large quantities of water are applied in irrigation; and the result is that the main Hermiston drain flows perpetually with a mean monthly discharge which ranged from 24 to 57 second-feet and a run-off which averaged 28,550 acre-feet per annum for the 3 years ended September 1931.[6] The water supply of West Extension Irrigation District during part of the season consists entirely of return flow. Its diversion is some 9 or 10 miles below the Hermiston drain and it receives, in addition, invisible seepage from Hermiston District and return waters from other irrigated lands above.

When the water supply in the Umatilla is only enough to fill the demands of decreed priorities the river is successively dried at four diversion points, all lower rights in turn being satisfied by return water flowing in the channel.

The extent to which diversions from this stream are dependent upon return water from irrigation may be illustrated by the results of gagings made over a 3-year period on the Umatilla (*28, Paper 694, pp. 16–17, 21; Paper 709, pp. 14–15, 19; Paper 724, pp. 15–16, 21*) and on Butter Creek.[6] The differences in run-off to Umatilla River

[5] CARBERRY, R. S., PRESTON, P. J., and HOLT, L. M. REPORT ON OPERATION AND MAINTENANCE METHODS AND PRACTICES ON FIFTEEN MAJOR PROJECTS, GOVERNMENT AND PRIVATE, JANUARY 1927, MADE TO THE COMMISSIONER OF RECLAMATION. 1927. (Unpublished manuscript.)

[6] Data furnished by State engineer of Oregon.

above Furnish Reservoir plus the inflow from Butter Creek and the run-off in the river near Umatilla (near its mouth), as compared with actual diversions between the points of measurement, in acre-feet per 12-month (October–September) period, were as shown in table 1.

The actual proportion of the excess due solely to return flow has not been determined. Some of it is due to rainfall and to unmeasured accretions, but return flow unquestionably accounts for a large part.

TABLE 1.—*Differences between upper and lower stations of Umatilla River, Oreg., total diversions and excess due largely to return flow*

Item	1928–29	1929–30	1930–31
Differences between upper and lower stations, presumably available for diversion	*Acre-feet* 162,000	*Acre-feet* 126,370	*Acre-feet* 131,460
Total actual diversions	235,052	213,776	209,378
Excess, probably due in large measure to return flow from irrigation	73,052	87,406	77,918

SACRAMENTO AND SAN JOAQUIN RIVERS, CALIF.

The Sacramento River occupies the trough of a valley about 150 miles long and mainly from 25 to 40 miles wide. Drainage from irrigation diversions returns quickly to the river, principally through troughs in the adjoining basins, and is discharged into the river through well-defined channels at considerable distances downstream from the diversion sources (*24, pp. 245–246*). Studies of return flow during the period 1924–28, made by the State Division of Water Resources (*24, p. 247*), show

> that the seasonal seepage, ground water return, etc., which can not be directly measured varied from a minimum of 11 per cent of the irrigation draft in 1924 to a maximum of 20 per cent in 1927; that the seasonal return as measured at the definite return channels varied from 22 per cent of the irrigation draft in 1924 to 40 per cent in 1925; and that the total return, including all accretions, varied from 33 per cent of the irrigation draft in 1924 to 59 per cent in 1925 and 1927.

Figure 1, showing the accumulated draft and return flow along a 200-mile section for June to September 1928, is redrawn after the report upon this work. Water known to be derived from sources other than return from Sacramento River diversions was carefully excluded from the amounts used in preparing the chart.

A feature of the return-water situation in Sacramento Valley is the large quantity of river water diverted for rice irrigation and the large proportion of such diversions returned to the river. Records of three typical projects over a period of 7 years showed the consumptive use to be essentially unaffected by the quantities diverted. As the soils were impervious, quantities in excess of evaporation and transpiration requirements returned promptly to the river and became available for reuse by lower projects. Large irrigating "heads" and large rice "checks" were used to reduce labor costs and to effect sufficient circulation of water both to wash out alkali accumulations and to prevent further alkali deposits (*26*).

The State Division of Water Resources has estimated from its water supply and return water studies that under a condition of ultimate

development about 42.5 percent of all water diverted for irrigation in Sacramento Valley would reach the streams as return water. The division further estimates that 75 percent of the total annual return would reach the streams during the irrigation months of April to October, inclusive; that the highest rate of return per month would be 13 percent from June to August, and the lowest 5 percent from November to March (*29, p. 80*).

Studies made from 1924 to 1928 by the State Division of Water Resources indicated that the average percentage of diversions occurring as return water in the San Joaquin River was considerably less than for the Sacramento, due probably to the recapture of much of the underground water by drainage pumps and its reuse for

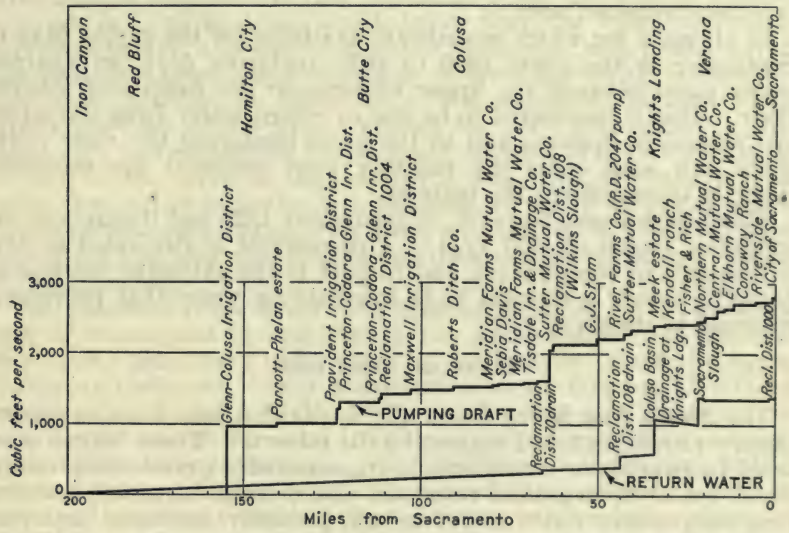

FIGURE 1.—Accumulated draft and return flow, Sacramento River, Calif., Red Bluff to Sacramento, June 1 to Sept. 30, 1928. (Redrawn from California Department of Public Works, Division of Water Resources Bulletin 23 (*24, p. 249*)). In order to show return water from Sacramento River irrigation only, the discharge to the Sacramento River of the Feather and American Rivers is excluded as is also return through Butte slough, a portion of the return through Sacramento slough derived from Feather River diversions and the return through the back borrow pit of Reclamation District No. 1000.

irrigation before reaching the stream. It was stated, however, that as all waters in the tributary Stanislaus, Tuolumne, and Merced Rivers normally are diverted by July or earlier at the foothills, and those of the San Joaquin are diverted near Mendota and Dos Palos, practically all water in these streams below those diversion points during most of the irrigation season is return water. The division found, on the one hand, some evidence of a considerable "lag" between diversions and return to the San Joaquin; and, on the other hand, evidence pointing to a surprisingly rapid response in the return water to certain diversions considerably remote. The return water average for July, August, and September ranged from 28 to 38 percent of the annual draft during the 5-year period studied (*24, pp. 342–345*).

KINGS RIVER, CALIF.

Upon leaving the foothills, canals serving a combined area of some 400,000 acres (irrigated in 1928) divert from Kings River quantities of water which during the 10 years ended with 1931 ranged from 221,000 to 1,058,000 acre-feet per annum. Just below these diversions the river with its connecting sloughs passes through a basin about 6 miles long and 1 to 3 miles wide, known as "Centerville Bottoms", which is irrigated by a number of small riparian ditches. Much of the water diverted by these riparian ditches drains directly back into the river within the basin. Some 13 or 14 miles below the outlet is the Peoples Weir, the first of a number of lower canal diversions, and on each side of the river throughout this distance is an extensive irrigated area.

In all cases for which records are available for the period May to September in the years 1920 to 1928, inclusive (*14*), an analysis shows gains between the upper entrance to the basin and Peoples Weir. This is considered to be due to return water from irrigation in Centerville Bottoms and in the areas bordering the river lower down. In some cases the monthly gain exceeded the combined monthly diversions in the bottoms.

There were losses, however, in September 1929 and throughout the irrigation season of 1931 (*14*).[8] This reversal is attributed in part to droughts of recent years, and in part to the extensive increase in pumping which is thought to be intercepting water that previously returned to the river.

SANTA ANA RIVER, CALIF.

The Santa Ana River Basin (*5*) is divided into 5 major basins, the river crossing 3 and separating the other 2.[9] These basins, separated by barriers or constrictions, are essentially gravel-filled valleys which act as underground reservoirs and contain "areas of intensive irrigation where water is put to use, partially consumed and partially sinking again as return water to underground storage" (*23, p. 38*). Underground waters not intercepted by pumping within a basin eventually come to the surface in the river bed above the dike which marks its lower end and flow out to the next lower basin. Irrigation waters, therefore, are reused again and again.

In a number of localities in Santa Ana Basin flood water has been spread over gravels to replenish the underground supply, principally since about 1910 but in some cases as early as 1895 or 1896 (*23, pp. 165–179*). For example, in the upper basin, which ends at Colton, the Water Conservation Association built spreading works below the canyon for the purpose of recovering the water at and above the outlet, at first principally in the gravity canals of the association members and later in artesian and pumped wells.

An analysis of summer consumptive use in the Santa Ana Basin was made in 1928 by the State division of engineering and irrigation (*23, pp. 158–161*). Certain values were assumed for transpiration and evaporation and such losses were deducted from assumed water

[8] KAUPKE, C. L. WATER MASTER REPORT FOR YEAR 1931. Kings River Water Association. 51 pp. Fresno, Calif. 1932. [Mimeographed.]

[9] A map appears opposite p. 18 in (5).

requirements, the result being estimated as return water or deep penetration from irrigation practice. The net loss or return calculated in this manner for the entire basin amounted to 30 percent of the water applied.

BOISE RIVER, IDAHO

Most of the irrigable land in Boise Valley, Idaho, south of the river, is included in the Boise project (constructed by the Bureau of Reclamation) and in several large irrigation districts, while the land now irrigated north of the river is served principally by a number of mutual irrigation companies in a comparatively narrow strip along the stream. The total irrigated from Boise River in 1929 was 318,496 acres (*27*). The river is divided for administrative purposes into three natural sections—the first beginning at the Boise project diversion dam and ending about a mile below Star, the second ending at the Notus bridge, and the third at the confluence with Snake River. The vital part played by return flow in river regulation is exemplified by the situation in 1931—one of the seasons of shortest water supply recorded on the river. During the low-water period of that year—July 1 to September 30—section 1 diverted practically all natural flow in the river, so that section 2 was supplied entirely from return flow; while in section 3 throughout the entire irrigation season all rights were supplied entirely from return flow.[10] The total river run-off for the year was 846,844 acre-feet and the total return flow 171,736 acre-feet.

The waters of Boise River have been adjudicated, except as to the duty of water, and in that regard the water master has followed since 1919 a temporary order made by the District Court of Canyon County and effective "until a further order of this court." Three drainage districts of Ada County (adjoining Canyon County on the east) in 1923 and 1925 secured from the District Court of Ada County orders temporarily apportioning the "developed" or drainage waters for the appropriation of which the districts had secured or were in process of securing permits from the State; prior existing rights on Boise River not to be interfered with. These orders were held later by the Ada County court to have been administrative only, in exercise of powers granted by the drainage district statute. In carrying out the orders, the water master turned into the heads of canals supplying these drained lands the quantities of water—within limits specified in the orders—that he ascertained upon the basis of the best available data as developed by the drainage systems and discharged into the river. In other words, these lands were given additional diversions from Boise River equivalent to the quantities of water determined as being developed by them.

Return flow to the Boise River has been an essential factor in supplying downstream priorities, as above indicated. In time of shortage the delivery of these drainage waters under the temporary orders referred to is considered by some of the Boise River users as cutting into their rights—which would undoubtedly be the case were the waters in question a part of the river flow. However, the questions as to public or private character of these drainage waters, as to

[10] WELSH, W. E. WATER DISTRIBUTION OF BOISE RIVER, DISTRICT NO. 12–A, 1931. Report by water master of Boise River to Commissioner of Reclamation. 21 pp., illus., Boise, Idaho. 1932. [Mimeographed.]

whether they are actually "developed" waters or would reach the river irrespective of the drainage works, and as to their ownership, have never been litigated in a proceeding competent to decide them. Furthermore, no comprehensive physical investigation of these drainage and "developed" waters has yet been made.

Return flow on this stream has been under observation for many years and has been the subject of a number of reports.[11] Controversies have arisen over the diversion of drainage water for irrigation, and the ownership of drainage waters was called into question in a recent case but was not decided because of the nature of the proceeding.[12]

There are other instances of the use of drainage water before reaching Boise River.

SNAKE RIVER, WITHIN IDAHO

Several groups of extensive irrigated areas lie along this stream in its course across southern Idaho, and in many sections return flow is an important part of the water supply. The ownership of return flow from the Minidoka project (Bureau of Reclamation) has been in controversy recently, but after being in court for about 5 years, the cause was dismissed without prejudice in 1932, by agreement of the parties, without deciding any of the questions at issue.[13]

The Minidoka project lies a short distance above Milner Dam, at which water is diverted for the Twin Falls tracts. Above the Minidoka lands is Lake Walcott Reservoir, and above this lake in turn is American Falls. The Neeley gaging station is located on the river just above Lake Walcott. The Foster decree, adjudicating the rights of users between American Falls and Milner Dam, entered upon stipulation in 1913, gave Twin Falls Canal Co. a right for 3,000 second-feet and North Side Canal Co. 400 second-feet, immediately prior to the Minidoka right of 1,726 second-feet. This decree also provided that the State engineer or his deputy should determine what part of the water flowing in Snake River at Minidoka and Milner Dams is storage and what part natural flow, "the amount of the natural flow to be determined as such natural flow would be, if unaffected by the diversions or acts of the parties hereto or any or either of them or by the release of stored water, * * *." The water master's affidavit stated that this language had been interpreted both before and after entry of the final decree as excluding the return flow of the Minidoka project from the natural flow to which the Twin Falls Canal Co. was entitled.

The net average daily gain in the river section between Neeley and Milner for the summer seasons of 1919 to 1930, inclusive, ranged from 1 second-foot in 1927 to 272 second-feet in 1929, averaging 111

[11] TULLER, W. H. REPORT TO BOISE PROJECT BOARD OF CONTROL OF THE DEVELOPMENTS TO DATE ON RETURN FLOW AND SEEPAGE STUDIES MADE ON BOISE RIVER. Boise, Idaho 1931. [Typewritten.] 14 pp.

[12] *Nampa & Meridian Irrigation District* v. *William E. Welsh, Water Master, et al.*, 52 Idaho 279, 15 Pac. (2d) 617. This was a petition for writ of mandate to compel the water master to distribute the waters of Boise River as directed by the Stewart decree. The court held that while the question of ownership of certain drainage waters had been thrown into controversy by the pleadings and evidence, such a matter could not be litigated in a mandamus proceeding.

[13] *Twin Falls Canal Co.* v. *George N. Carter et al.*, District Court of the United States, District of Idaho, Southern Division.

for the period.[14] Under the interpretation of the Foster decree referred to above, the Minidoka canals were given this gain at such times as they were drawing stored water. In other words, the decree has been administered according to the water stages at Neeley: whatever amount of water belonging to Twin Falls Canal Co., for example, was found at Neeley, that amount was delivered to the company at its Milner diversion. It was to obtain the benefit of this increment during low-water stages of the river—when the flow at Neely is less than enough to satisfy the Twin Falls rights—that this action was brought by the company. Dismissal of the complaint leaves the situation as it was before; the State administrative officers determining storage and direct flow according to the Foster decree.

The drainage discharge from the Twin Falls tracts is likewise considerable. The average discharge of all developed drains on the Twin Falls Canal Co. project, measured in the spring and fall with all water out of the irrigation system, ranged from 129,000 to 176,000 acre-feet per annum during the period 1928–33. This drainage discharge, during the period 1931–33 for which information is available, was less than one-third of the total run-off from the project; and the total run-off in turn, during that 3-year period, constituted 39 percent of the total water diverted.

PROVO RIVER, UTAH

The Provo River system in Summit, Wasatch, and Utah Counties serves an upper agricultural area lying mainly in Wasatch County, converges at Provo Canyon, and then serves a lower area in Utah Valley. All drainage from the upper area is through this canyon. Early settlement and use of water were in and around Provo in the lower area. As settlement progressed upstream, demands upon the water supply of the river increased to such an extent that the lower users claimed that their rights—many of them prior in point of time—were being infringed upon. Naturally this led to many conflicts and much litigation. However, subsequent developments seemed to indicate that in the long run upstream use during at least a part of the season was a benefit rather than an injury to lower lands, in that the storage of water in these upper lands and its gradual release tended to prolong the seasonal supply in the lower river. The adjudication of Provo River took account of this situation, and resulted in good rights for both upper and lower appropriators. Return water from irrigation is specifically decreed a part of the stream supply; in order to insure its continuance, none of the upper users (Wasatch and Summit Counties) may extend

> the use of the waters awarded to them upon other lands than those now irrigated so as to cause the seepage or drainage therefrom to be diverted away from the channel of said river or from the lands heretofore irrigated thereby.[15]

One of the parties to the adjudication (Esthma Tanner), owning land about 5 miles below the mouth of Provo Canyon, claimed the right to take from the river a quantity of water equal to the quantity of drainage water discharged into the river from such land.

[14] CRANDALL, L. REPORT OF WATER MASTER, DISTRICT NO. 36, IDAHO, FOR 1930. 1931. [Typewritten.]

[15] Findings of Fact and Conclusions of Law, *Provo Reservoir Co. v. Provo City et al.*, Utah County, signed May 2, 1921.

Lower appropriators with old-river rights, which were being satisfied during part of the season by seepage from bench lands, feared that the substitution of direct flow for drainage water might interfere with their own right to demand direct flow during periods of deficiency in the seepage accretions, and accordingly protested. In order to safeguard all appropriators below the drainage ditch, the adjudication authorized such substitution only while direct flow is turned down to supply seepage deficiency, and only to the extent of the quantity of drainage water discharged from such tract into the river. In other words, when direct flow is being sent down on demand of the lower users this tract may take a part of such water equivalent to its own drainage discharge, but otherwise cannot demand direct flow in substitution for return flow.

SALT RIVER, ARIZ.

Recognition of the effect of return flow upon irrigation is of long standing in Salt River Valley, for it is a common occurrence for canals during low-water stages to dry the river, one after another, at their respective head gates. For example, on May 1, 1932, when flood conditions were not prevailing, all water flowing in the river, consisting of 70,000 miners' inches, was being diverted at Granite Reef by the Salt River Valley Water Users Association. More than one-half of this dam rests upon bedrock, and the depth to rock beneath the other portion is shallow; consequently in the opinion of certain local engineers the underflow is small or nonexistent except when the stream bed above has been badly stirred by a flood. It is, therefore, likely that at this time practically all of the subsurface as well as the surface flow was being diverted. As there were no living streams between that point and the junction of the Salt and Gila Rivers, it follows that diversions at that time between those points may be safely attributed principally to return waters from the Salt River project. Joint Head, Peninsula, and Horowitz, and the Indian ditch diversions successively took the entire river flow on May 1 (although there was leakage through the two last-named diversion structures)—with an aggregate of 2,567 miners' inches—yet the Salt River delivered 3,445 inches into the Gila on May 2.

The figures in the foregoing paragraph do not include underflow in the Agua Fria below the Salt-Gila junction or pick-up below that point, which in one or both cases was considerable. Nor, due to the extensive pumping on the Salt River project, do they provide any measure of the total amount of water that otherwise would have returned to the river. Pumping for drainage on that project and reuse of the water for irrigation constitute an important feature of this area (*15*).

NORTH PLATTE RIVER, COLO.-WYO.-NEBR.

The North Platte rises in northern Colorado, flows north into Wyoming, and thence southeast and east across Nebraska, being joined in the central part of that State by the South Platte. The area now irrigated from this stream in Colorado is relatively very small, but studies have been made of the possibility of capturing a large part of the tributary inflow in North Park and diverting it to

Cache la Poudre Valley. The most extensive development of this stream in Wyoming and Nebraska has been by the Bureau of Reclamation. In addition, one large and numerous small projects have built diversion and distribution systems, and some have contracted with the United States for storage rights in Pathfinder Reservoir.

Determinations of the amount of river gain have been made from time to time, a systematic series of measurements aimed at determining the amount of return flow having been begun in 1914 (*30*). With the development of the large projects above Bridgeport and the installation of drainage systems the amounts of both visible and invisible return to the river have become very great. A recent study (*7*) shows that the total increase in the North Platte, between Whalen Dam and the city of North Platte, for the year ended September 30, 1931, was 1,574,700 acre-feet, of which 540,300 acre-feet occurred during the irrigation season May to September. As a means of approximating the quantity of return flow included in this gain, the annual figures were corrected for flow from all known sources other than irrigation, for rediverted return flow, and for evaporation losses. The result was:

	Acre-feet
Visible gain:	
Above Bridgeport	609,700
Below Bridgeport	106,200
Invisible gain:	
Above Bridgeport	368,700
Below Bridgeport	173,800
Total	1,258,400

It was concluded that the greater part of the increase in flow above Bridgeport was return flow from irrigation, and that below Bridgeport a large proportion of the invisible increase was foreign ground water.

The effect of return flow above Bridgeport upon diversions below that point is strikingly brought out by a chart prepared in the office of the Bureau of Irrigation, Water Power, and Drainage of Nebraska and presented in somewhat different form in figure 2. The river flow at each station is taken from (*17, pp. 338–345*), as of the time when the water released from Guernsey Reservoir at 6 p.m., August 1, 1929, would reach that station if flowing at an average rate of 35 miles per 24 hours. "Pick-up" includes both visible and invisible increase.[16] The quantity flowing in the South Platte (the only important surface tributary to be considered in this connection) at the city of North Platte on August 8 was only 2 second-feet.

Figure 2 shows that during the period considered the quantity of original flow and storage water released from Guernsey Reservoir on the evening of August 1 was sufficient to care for diversions only as far down as Melbeta. From there to Overton, except for a small quantity of storage, all diversions were from "pick-up" which undoubtedly consisted principally of return waters from irrigation. The quantity of water released from Guernsey at that time was 5,750 second-feet; the aggregate quantities diverted in the 10-day procession down the river were 7,964 second-feet.

[16] It should be noted that the Bureau of Irrigation of Nebraska and the Federal Bureau of Reclamation were not at that time in agreement as to the rate of evaporation at which "pick-up" should be computed.

SOUTH PLATTE RIVER, WITHIN COLORADO

The early recognition of return flow to the South Platte and its largest tributary, the Cache la Poudre, has been shown above. The river flows north and northeast from Denver across the plains in a well-defined valley, the river bottom being confined between bluffs which throughout considerable distances are very sandy. The progressive construction of larger and longer ditches and of reservoirs, which have provided water for expanding areas, have created more and more return flow to the river (*22, pp. 4–11*).

Parshall reports a total net return flow between Kersey (just below the mouth of the Cache la Poudre) and Julesburg (near the Colorado-Nebraska State line) amounting to 184,510 acre-feet for the approximate period July 1–November 10, 1919, and 474,840 acre-feet for January 1–November 10, 1920 (*22, pp. 31–36*). The relation borne by return flow to irrigation in the South Platte Valley

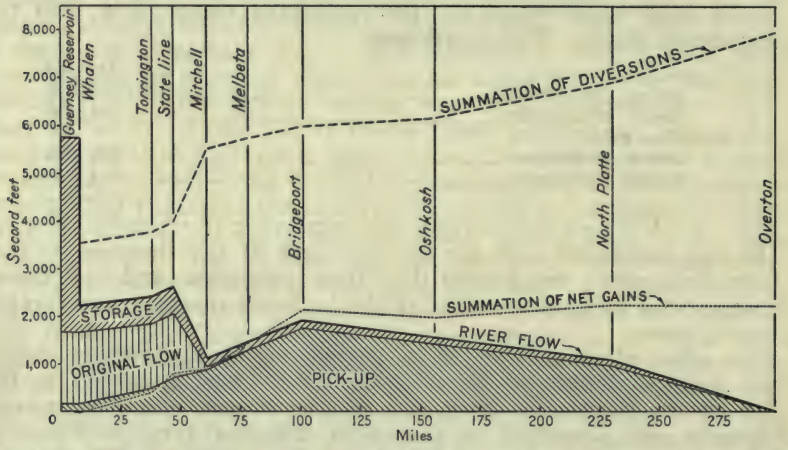

FIGURE 2.—Effect of return water from irrigation upon canal diversions from North Platte and Platte Rivers, Wyo. and Nebr., from Guernsey Reservoir to Overton, August 1, at 6 p.m., to August 10, at 2 a.m., 1929.

may be further illustrated by the statement that during the period in 1920 just referred to, the flow of the South Platte at Kersey totaled 472,682 acre-feet, the inflow of lower tributaries being comparatively small; that 169,630 acres were reported irrigated in districts 1 and 64 with an aggregate application of 457,837 acre-feet, which nearly equalled the flow at Kersey; yet the river flow at Julesburg, below this area, for that period amounted to 259,782 acre-feet, or 55 per cent of the flow at Kersey (*22, pp. 31, 36, 66, 67*).

The latest published report on seepage and return flow to the South Platte is in the State engineer's biennial report for 1929–30 (*13, pp. 45–59*). A series of measurements in 1930—Kersey to Julesburg in April, and Waterton to Kersey in May—revealed a total seepage return of 1,467.4 second-feet for the river, which, if representative of the entire year, means an annual return of approximately 1,000,000 acre-feet. Figure 3, reproduced in slightly different form from this report, shows the return flow measured at intervals

over the period 1891–1930. The report concludes that since 1916 the rate of increase of seepage return appears to be approaching the ultimate, although irrigation has been gradually increasing. "This would seem to indicate that the pervious water-carrying strata through which the seepage returns to the river, is nearing its carrying capacity" (*13, p. 45*).

ARKANSAS RIVER, WITHIN COLORADO

The Arkansas River leaves the mountains just west of Pueblo, Colo., and flows in an easterly direction across the State into Kansas. The waters of this river were involved in the noted interstate case of *Kansas* v. *Colorado*,[17] and at the present time are again being litigated in a suit between those two States. Many irrigation projects dependent upon this stream and its tributaries lie along its

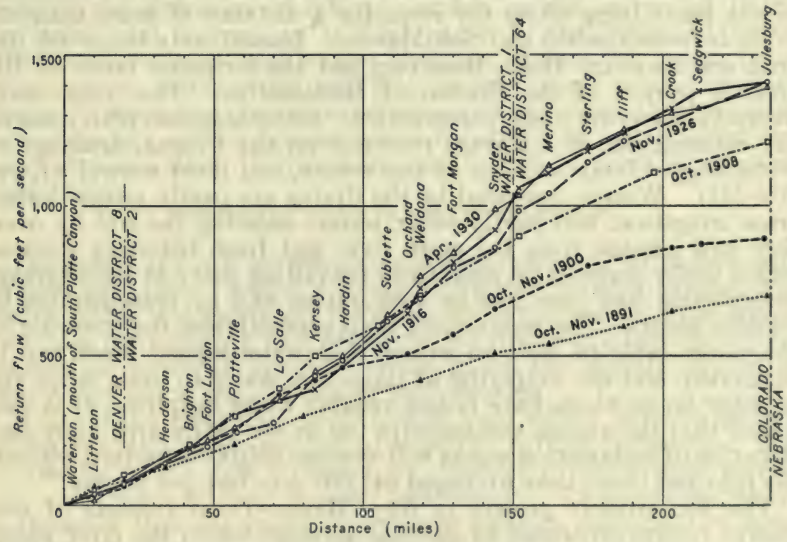

FIGURE 3.—Measured seepage return flow to the South Platte River between Waterton and Julesburg, Colo., 1891 to 1930, inclusive (*13, p. 59*).

course, the irrigated areas in most cases being not far from the river. Investigations made to the year 1926 by the State engineer of Colorado indicate that the total invisible seepage and return flow along the main stem of the river throughout its length in Colorado amounted to substantially 200,000 acre-feet per year, such amount, however, varying materially from season to season (*13, p. 45*).

RIO GRANDE, COLO.–N.MEX.–TEX.

The Rio Grande rises in southern Colorado, flows south through central New Mexico, and thence continues southeasterly between Texas and Mexico to the Gulf of Mexico.

Rio Grande waters are diverted by a number of irrigation systems in San Luis Valley, Colo. The northern part of this valley com-

[17] *Kansas* v. *Colorado et al*, 206 U.S. 46.

prises a so-called " dead area " respecting drainage. There is a ridge running roughly parallel to the river on the north; south of this ridge the drainage is toward the river, and north of the ridge the drainage is away from it. On the north drainage water reaches a trough and forms swamps and lakes with no known outlet to the river. Some 240,000 acre-feet per year drain into the dead area as a result of natural run-off, and in addition 300,000 to 400,000 acre-feet are diverted into this area annually from the Rio Grande by canal systems (*13, pp. 38–39*); therefore, when this area shall have been drained to the river a considerable addition to its water supply will result. The valley ends a short distance south of the State line and the river enters mountainous country, so that the portion of return water from irrigation not trapped north of the ridge or otherwise lost is forced back into the stream channel.

The Middle Rio Grande Conservancy District of New Mexico includes lands lying along the river for a distance of more than 150 miles between Cochiti and San Marcial. Immediately below the district are Elephant Butte Reservoir and the irrigated lands of Rio Grande project of the Bureau of Reclamation. The conservancy district's works are under construction. Its reclamation plan includes the construction of a storage reservoir on the Chama, drainage of water-logged lands and use of the waters, and flood control (*1, pp. 109–134*). Waters recovered by the drains are partly return waters from irrigation, and partly other waters entering the soil by overflow and seepage from the main river and from tributary streams, which under water-table conditions prevailing prior to the drainage construction had been lost by evaporation and by transpiration by aquatic plants. The reclamation plan contemplates the lowering of the water table to such an extent that water-logged lands can be cultivated, and the supplying of irrigation water to those lands and to other lands which have lacked reliable water supplies. It is estimated that the annual consumptive use in the entire area after construction of reclamation works will average 490,000 acre-feet, whereas the previous losses have averaged 541,000 acre-feet per annum.[18]

The Rio Grande project in New Mexico-Texas consists of successive valleys separated by canyons through which the river passes from one valley to another. The largest sections are Rincon, Mesilla, and El Paso Valleys. The project is provided with extensive drainage systems which return to the river much water that has been used in irrigation. The drainage water, mingled with direct-flow and storage waters, is partly diverted into lower canal systems on the project.

Most of the irrigation along the Rio Grande below the Federal project is in Lower Rio Grande Valley, where 350,000 acres are under cultivation on the American side between Riogrande City and the Gulf. Here return water does not reach the river. On the contrary, nearly the entire area is a delta formation, in which the characteristic slope of the land is away from the river. The drainage outlets lead to the Gulf, not to the river. Drainage water is recovered and reused for irrigation to some extent, however, several small projects depending upon such water for a substantial part of their irrigation supply.

[18] DEBLER, E. B. FINAL REPORT ON MIDDLE RIO GRANDE INVESTIGATIONS. U.S. Dept. Int., Bur. Reclam., 157 pp. illus. 1932. [Typewritten.]

ECONOMIC IMPORTANCE OF RETURN FLOW IN STREAM UTILIZATION

CONFLICTS OVER OWNERSHIP AND USE OF RETURN WATERS

NATURE OF CONTROVERSIES

Conflicts over return waters have arisen in all or nearly all of the irrigation States. In the course of the present study notes were made of more than 40 such cases in 13 States, involving the right to use seepage waters under a wide range of circumstances. Many controversies were settled as a result of court decisions.

Specific questions involved in these disputes were the right of a project to recapture its own seepage waters, or to substitute them for the diversion of direct flow, and the method of substitution; the right of downstream users to take return waters yielded by upper projects; the alteration of drainage outlets, or the capture of drainage water and delivery to a third party, to the injury of lower diverters of such drainage water; diversion of waters to points from which return water could not find its way back to the original stream; intercepting underground waters on their way to the stream; refusal to pay agreed compensation for drainage waters; and the value of return flow. Entire water rights were involved in many of these cases.

RELATION OF PUBLIC OR PRIVATE OWNERSHIP

The public and private attributes of ownership of return flow will be dealt with later. Suffice it to say that under the public-ownership theory return waters are not the property of the project from which they flow, but become a part of the stream system available to appropriators in order of priority; while under the private-ownership theory they are at the disposal of such project.

Many of the foregoing controversies were settled without specific reference to the broad question of public or private ownership. The peculiarity of the local situation, or injection of other legal points, frequently made a broad decision unnecessary. In some instances it is apparent that the parties purposely avoided bringing the main question to an issue. Consequently, despite the widespread occurrence of controversies, clear-cut court decisions as to the general policy are confined to a few States.

WATER RIGHTS DEPENDENT UPON CONTINUANCE OF RETURN FLOW

In many sections of the West extensive development has taken place with water rights predicated wholly or partly upon return flow. This is evident from the examples listed heretofore. In certain cases, such as the Provo in Utah, downstream development occured first, and return flow from later upstream diversions not only satisfied the demands of earlier appropriators but actually worked to their benefit. Again, as on the South Platte in Colorado, development progressed downstream in step with increasing return flow from upstream projects. The two situations are comparable physically, and in each case junior water rights improved as a result of return flow; but the benefit to holders of junior rights on the Provo is from their own use of water, while on the South Platte

it is from use by others. From a legal standpoint, return flow on the Provo must continue to go to lower users on the ground of priority; upstream users cannot extend their use of water to include their own return flow, for such action would injure the downstream prior appropriators. As long as return flow continues, the earlier users can have no complaint. But the South Platte situation is different, and there the safety of the lower development depends upon some other rule of law—public ownership of return waters, or prescriptive right, or estoppel—which will prevent upstream users from diverting their return waters elsewhere. It is shown hereinafter that the public-ownership rule is well grounded in Colorado, and so the lower development on the South Platte is protected on that ground at least.

There are other situations in which lower development depends upon continuance of return flow, in jurisdictions in which the character of ownership has not been definitely established beyond argument one way or the other. Boise River in Idaho and Salt River in Arizona are examples of this. The controversy over substitution of direct flow for drainage discharge on the Boise and the fact that there has been no decision in the State courts regarding ownership have been indicated in the discussion of that stream. Administration of Boise River priorities has assumed that return flow (except in case of certain drainage districts) is available for lower diversion. If return flow is increasingly rediverted by projects from which it flows—or direct flow substituted, which amounts to the same thing—the basis of administration must be changed.

Salt River Valley Water Users' Association installed a line of pumping plants, within its boundaries and a few miles from the river, from which water is conveyed to another organization, the Roosevelt Irrigation District; and eventually several lower diverters from the river complained that their water supply was being affected by the pumping. An arrangement was voluntarily made by which these diverters were provided with water to supply deficiencies in their decreed rights. The association had been upheld by the courts in its right, as against a shareholder, to drain lands and dispose of the water for compensation outside the project. The rights of other persons, however, were not involved, and the legal consequences of a possible depletion of their water supply by the diversion of pumped waters elsewhere were thus not passed upon.[19]

DIVERSION AND USE OF PERCOLATING WATERS

The right to pump or otherwise divert percolating waters is a correlative right with other overlying landowners in certain States, including California; depends upon compliance with an appropriation statute in one, New Mexico, and in portions of Oregon (not yet passed upon); and goes to the overlying landowner in others. In a Utah controversy it was ruled that percolating return waters on their way to a stream on which appropriation rights had been established could not be intercepted by the owner of land through which they were passing, if such action substantially interfered with prior river rights.[20]

[19] *Brewster et al* v. *Salt River Valley Water Users' Association et al.*, 27 Ariz. 23, 229 Pac. 929.

[20] *Rasmussen* v. *Moroni Irrigation Co. et al.*, 56 Utah 140, 189 Pac. 572.

One method of draining irrigated land is to pump the water out. This practice is notable in Salt River Valley (*15*); several California projects do it on a large scale, and numerous instances could be cited in other States. Drainage water so recovered by an irrigation project is commonly used for irrigation purposes. In most cases that have come to the author's attention the reuse has been on the project doing the pumping and has not been in controversy with users whose stream diversions might be expected to be affected. Diversion of the recovered water to another project is more likely to result in controversy.

APPROPRIATION OF WASTE WATER

Avoidable waste of water is contrary to public policy. It tends to deprive a lower user of a supply which he is entitled to receive. However, the statutes and court decisions recognize that some so-called waste is inevitable and may be appropriated to beneficial use.

Several of the State codes provide that ditches for the utilization of waste, seepage, or spring waters shall be governed by the same priority rules as ditches from running streams; also that the person on whose land seepage or spring water arises shall have the first right to its beneficial use on his lands. Colorado, among other States, has such a statute; but the courts there have held that the landowner does not have this first right where seepage waters first come to the surface in the channel of a natural stream [21]; nor where they belong to a stream and would reach it if not intercepted.[22] In New Mexico the first right to seepage from constructed works may be acquired by the owner of the works if he makes filing within 1 year after completion of construction or appearance of the seepage, and thereafter by anybody. Some of the statutes specifically direct an appropriator to turn back to the stream from which he makes his diversion all water in excess of his needs.

Water returned to a stream, after having been used in irrigation and relinquished by the appropriator, becomes a part of the stream again. This is a general rule. If the appropriator does not relinquish control—that is, if his plans include the commingling of such water with that flowing in the river, and its rediversion by himself or others with his consent farther downstream—there is obviously no abandonment. He is simply using the river channel as a carrier, as is commonly done with reservoir water stored upstream. The courts of Colorado do not sanction this practice in case of return flow, but definitely consider water once released from a project (irrespective of the owner's intentions) or seeping from its reservoir as not subject to recapture by that project either before or after reaching a natural channel. Any appropriation of that water is subject to all prior appropriations from the river.[21] Exceptions are noted below under Developed or New Water.

Waste water from irrigated lands may be captured by the first user, except in those jurisdictions (for example, Colorado and probably Utah) in which it is considered tributary to streams. However, the person capturing the waste, although protected against interfer-

[21] *La Jara Creamery and Live Stock Association* v. *Hansen*, 35 Colo. 105, 83 Pac. 644.
[22] *Nevius et al.* v. *Smith*, 86 Colo. 178, 279 Pac. 44.

ence by later comers, has no right to compel the continuance of that waste. The project on which the waste originates may make such economical use of its appropriation that but little water will be left over, or can rearrange its distribution so that waste at a given point ceases, or can alter the drainage outlet if advantageous to do so. The only equitable restriction is that it cannot maliciously divert the waste water elsewhere simply to deprive the lower user of a water supply. These matters depend solely upon the facts in the case. Several appropriations of drainage water directly out of drainage ditches have been made in the Lower Rio Grande Valley, Tex., in situations in which the water would not have returned to the river, the appropriator making a contract with the project owning the drainage system which protects him against alteration of the drainage outlet, and securing a permit from the State which gives official sanction to his appropriation. In the administrative practice of the State of Nebraska the location of a diversion headgate on an artificial drain is treated as an optional diversion; the appropriation is considered to be from the stream system, and the headgate location a matter of convenience or efficiency only. The applicant is deemed to be appropriating river water—not waste.

THE QUESTION OF A DOUBLE APPROPRIATION

If in addition to its head-gate diversion a project also rediverts its waste water, is it exceeding its appropriation? This point was directly involved in a request by Farmers' Irrigation District, Nebraska, to the State in 1932 for permission to divert a quantity of water equivalent to the discharge of one of its principal drains. The district claimed that the statutory duty of 1 second-foot to 70 acres, measured at the head gate, was insufficient in view of the seepage and evaporation losses from its 80-mile canal, whereas the requirements of a small project with similar soil and crops but with a short canal were capable of being satisfied. The request was denied on the grounds that (1) to add the drainage water to a full head-gate diversion would exceed the statutory duty; and (2) to add the drainage while the head-gate diversion was being cut below its decreed priority would deprive lower appropriators of public water to which they were entitled during periods of shortage. The view of the Nebraska authorities, although not passed upon by the State courts, is that return waters are public property.

The project claimed in the foregoing instance that its diversion was less than needed for beneficial use. If substantiated, there would have been no objection on the part of the State administration to beneficial use of the drainage before it left the project. The criterion was that the right to further use was lost on returning to the North Platte.

POINT OF DIVERSION OF RETURN WATERS

The point at which return waters are to be recaptured for irrigation is apparently of considerable moment, from a legal standpoint, at least in some jurisdictions. From a physical standpoint it is of course highly important.

BEFORE REACHING STREAM CHANNEL

The right to redivert and reuse drainage entirely within a project is not being seriously questioned, so far as the author is aware, in any of the States. An important precedent was set by the United States Supreme Court in the case of *Ide et al.* v. *United States*,[24] which arose on the Shoshone project in Wyoming. It was there held that the right of the Government in water appropriated for the reclamation project attached to seepage from the irrigated lands, "affording the Government priority in the enjoyment thereof for further irrigation on the project over strangers who seek to appropriate it for their lands." The court stated that there had never been any purpose to abandon the seepage, but on the contrary the intention to reuse it had been stated in official reports and otherwise made evident many times. The extent to which this ruling and the ruling of the Utah Supreme Court in the earlier case of *Rasmussen* v. *Moroni Irrigation Co. et al.* conflict is open to some question. In the Rasmussen case it was stated that the person recovering return water from higher lands on its way to a stream could use the water on the lands from which drained, and could "use it, or any part of it, upon lands other than those from which it is drained if such use can be made without interfering with respondents' prior rights."

The right of recapture after water leaves the project from which it drained and before it reaches the stream channel from which it was diverted, or at least before the waters are commingled with those of the original stream, apparently is still a moot question in most of the Western States except Colorado. Conveyance of return waters from one project to another in an artificial conduit, and extension of the area of a project by virtue of the reuse of return waters are other phases of the general question concerning which the law in most States is not definitely settled. These things have all been done in actual practice in various places, sometimes with consent of the State authorities.

REDIVERSION FROM STREAM CHANNEL INTO WHICH DISCHARGED

Use of the stream channel as a carrier depends upon the right of the project to control its return flow. If it may send this water elsewhere, the stream channel is a convenient and under some circumstances an economical carrier. Legally, of course, this is out of the question in Colorado. It is common practice in New Mexico, particularly along the Pecos; although in these instances the return is largely from irrigation from artesian sources not tributary to the Pecos. A Federal decision arising in Idaho [25] stated that an appropriator, provided he could identify the return flow, "may conduct it through natural channels and may even commingle it or suffer it to commingle with other waters." Incidentally, this language was quoted approvingly by the United States Supreme Court in another case.[24]

[24] *Ide et al.* v. *United States*, 263 U.S. 497, 68 L. ed. 407.
[25] *United States v. Haga et ux.*, 276 Fed. 41.

SUBSTITUTION OF DIRECT FLOW OR STORAGE WATER FOR RETURN FLOW

The diversion of drainage water and its reapplication to the soil are sometimes so expensive as to be uneconomical. Situations as favorable as that on the Wapato project, Washington, are exceptional. At the other extreme are projects on which the return becomes visible at places so low in elevation or so near the lower end of the area that only by means of pumping can it be redistributed. Substitution of direct flow, to be diverted at the head gate upstream, for the quantities returned to the stream below, has appeared to offer a more satisfactory solution.

Substitution would not be sanctioned under even the private-ownership theory of return waters if it interfered with diversions between the project's head gate and the point of discharge of the drainage water. That is, if the increased diversion, which is practically a transfer of the diversion point upstream, deprived an intervening user of any quantity needed to fill out his priority at his existing head gate, a court decision upholding the transfer is not to be anticipated. If there are no such intervening diversions to be considered, the proposed substitution depends upon the right to redivert drainage from the stream into which discharged. Clearly, if this right exists, transfer of the diversion point upstream does not deprive lower users of any quantity of water to which they are entitled.

Examples of substitution are to be found in several States, and the courts and authorities sanctioning the transaction have taken the position that if a project has the right to reuse its return flow it should be permitted to do so in the most economical manner possible. Several drainage districts along the Boise River have operated under this method of substitution for some years. The section of Snake River opposite the Minidoka project is so regulated that that project is credited with the amount of its drainage discharge. The plans of Middle Rio Grande Conservancy District involve substitution. Talent Irrigation District, Oregon, is permitted to divert upstream a quantity equivalent to its drainage picked up by Medford Irrigation District, which otherwise has the prior right on Bear Creek, the waters in question having been stored and brought across from another drainage area. Vale and Warmsprings Irrigation Districts, Oregon, have a contract under which Warmsprings exchanged a portion of its reservoir space and of its direct-flow rights for equivalent return flow from Vale District available for diversion into Warmsprings canals. The Provo River adjudication in Utah includes one case of limited substitution. Certain adjudications in Washington embody the principle, although a recent decree provided definitely that return seepage waters belonged to the stream.

Only one State supreme court case specifically passing upon this practice has come to the author's attention. In that case, involving the adjudication of Stemilt Creek, Wash.,[27] the decision was to the effect that if the parties have the right to use this seepage water and permit it to flow into the creek,

> then it would seem but just and equitable that they should be permitted to take an equal amount of water, less transportation loss, from some point

[27] *The State of Washington* v. *American Fruit Growers, Inc., et al.*, 135 Wash. 156, 237 Pac. 498.

higher up the creek, from which point it can be conveyed to their land by gravity; provided, of course, that by so doing they do not injure or interfere with the rights of anyone else.

The sole controversy was over the matter of substitution. The right to use the seepage water was not being contested, and the court therefore specifically refrained from passing upon that right.

RIVER CONSUMPTIVE USE IN RELATION TO SUBSTITUTION

Many streams in the West have very little water unappropriated; in such cases further development of any consequence is possible only through consumptive use of the relatively small remainder.[28] This involves the control of return flow from the project, which is legally possible only in certain jurisdictions. That is, if an average annual run-off of 25,000 acre-feet is determined as available, and the farm use is estimated as 2.5 acre-feet per acre but the river consumptive use as 1.25 acre-feet per acre, then 20,000 acres of irrigated land will be the maximum area on which water charges can be safely based, and plans must provide for the utmost conservation and careful use of this available remainder. Ordinarily, assuming that the available supply continues to be 25,000 acre-feet, at no time is the project diversion held to 1.25 acre-feet per acre. That is the river use, not the farm use. In the early stages of development the river supply plus rainfall is sufficient to fill the farm requirement of 2.5 acre-feet per acre; and as more and more lands are brought under cultivation and return flow becomes evident, a substitution at the head gate of the equivalent of this return flow leaves all lower rights undisturbed and at the same time fills the new project requirements.

An arrangement such as the above, involving a substitution of return flow for direct flow, but in a situation in which storage facilities are out of the question, presumably would not be feasible in a jurisdiction in which return flow automatically becomes public water. That is, the project could divert whatever excess of direct flow there might be above the requirements of earlier lower projects; but after, say, July 1, when there is no excess, diversions must cease, for the lower users could demand that the return flow come down to them as their lawful heritage. In such event the late project, if it cannot redivert the return flow advantageously within its own borders, cannot predicate its requirements upon consumptive use, but only upon early-season direct-flow supplies, as long as they are available. Therefore the project area must be held to considerably less than 20,000 acres, and the crops must be confined to those benefited by early irrigation. Instead of leaving the river as it was before, as far as lower rights are concerned, the late project is adding to the value of these lower rights by giving them a longer season of full supply than they enjoyed previously.

Middle Rio Grande Conservancy District plans include the rediversion or substitution of developed drainage waters in addition to storage development. Storage in the district's El Vado Reservoir would reduce the supplies available for storage in the Rio Grande project's Elephant Butte Reservoir if it were not for return flow

[28] "Consumptive use" has been defined by R. I. Meeker as "The permanent water loss incident to irrigation of large tracts of land * * * the difference between the amount of water diverted and the amount returning to a stream" (*12, p. 1350*).

and drainage waters developed by the district. In other words, the district's drainage-water development is intended to make good the depletion of the total river supply occasioned by additional diversions of water for irrigating the conservancy-district lands now unirrigated or inadequately supplied with water. Engineers of the Bureau of Reclamation, after a thorough study of the situation under a cooperative agreement with the conservancy district, "concluded that from the standpoint of water supply, the proposed development of the Middle Rio Grande Conservancy District will not injure the Rio Grande project." [29] The New Mexico laws provide that where a conservancy district "conserves, develops, or reclaims water, it shall have the rights which go with the appropriation and beneficial use thereof" (*21*). The district extends many miles along the river, and apparently there are no other users whose rights are interfered with.

DEVELOPED OR NEW WATER

Water brought to the surface in artificial drains is occasionally referred to as "developed" water. A more careful use of the term would exclude water tributary to a stream and which, while facilitated in its passage by the drains, would reach the stream eventually irrespective of them. Such water is not new water; the time of its arrival is simply hastened.

Water which, except for drainage installations, would not reach the river at all is more properly termed "developed" water. For example, the drainage plans of Middle Rio Grande Conservancy District "will lower the water table a sufficient distance below the surface to reduce greatly the present loss of water, thus effecting an actual development of water now lost to all beneficial use" (*1, p. 95*). Again, in Idaho the Ada County drainage districts are delivering to the Boise River waters which are actually saved from evaporation in swamps, as well as water which would reach the river in any event. The water master on the Boise applies a factor in calculating the portion of drainage which should be considered developed water and which under temporary court orders he credits to the irrigated lands in those districts. It is rather generally considered that the person or project responsible for such artificial increase in flow is entitled to its use or disposal.

Return from foreign water—for example, brought in from another watershed—is similar to developed water in that it is not considered tributary to the stream into which it is being made to flow by reason of the irrigation and drainage works. As far as lower users are concerned it also is new water. Even in Colorado, which appears so thoroughly committed to the public-ownership theory, water diverted from the Rio Grande, applied in the "dead area" from which it could not return naturally to the river, and brought back into the Rio Grande watershed in an artificial drain, was held subject to appropriation by the first taker over the protest of earlier appropriators from the river who claimed that it belonged to them.[30] To the same effect are Washington and Idaho cases in

[29] DEBLER, E. B. See footnote 18.
[30] *San Luis Valley Irrigation District, et al.* v. *Prairie Ditch Co. and Rio Grande Drainage District, et al.*, 84 Colo. 99, 268 Pac. 533.

which waters were brought in from other watersheds.[31] In the adjudication of Pecos River, N.Mex., which was in progress when the area was visited in 1932, stipulations were being taken providing for the discharge into the river and the subsequent recovery of drainage waters originating from artesian sources and therefore not a part of the original river supply. The administrative practice of the State of New Mexico has been to approve applications to appropriate drainage water discharged into a stream (minus carriage losses) where filed by the owner of lands or the project on which the drainage originates, or by a second party who has contracted with the first for the acquisition of those waters. Many of these contracts are in existence. Most or all of such cases are on the Pecos and have involved return waters from foreign artesian sources, but in a few instances there was included some return from springs which formerly flowed into the Pecos.

A different but somewhat allied question was presented when Waterford Irrigation District, California, applied for a permit to appropriate waste waters from storage reservoirs and power plants of the city of San Francisco. The application was based upon sections of the California statute authorizing temporary appropriations of water already appropriated for municipal use but as yet in excess of municipal needs, and authorizing the appropriation of water after it has been appropriated or used and returned to a stream. Modesto and Turlock districts claimed prior rights to these waters and protested the granting of the application. The permit was issued, subject to the city's prior rights on completion of the works and beneficial use of the water. The principal ground was that these released storage waters were foreign in point of time to the direct flow of the river during the irrigation season. Prior storage rights of the protesting districts were considered amply cared for.

CONTRACTS FOR DISPOSAL OF RETURN WATER

Agreements transferring the use of return waters from one enterprise to another are in effect in a number of States. Several have been cited heretofore in this discussion. Some involve water which, if not intercepted, would return to the stream from which diverted, and others deal with so-called " foreign water."

The Warren Act contracts in connection with the North Platte project provide that the United States will store water in Pathfinder Reservoir or elsewhere and release the same into the river, and will supply water from other sources for the use of the contracting enterprise, with the right to deliver drainage or seepage waters as a part of the total delivery. This provision for substitution of seepage for storage and direct flow is not in line with the practice of the Nebraska State Bureau of Irrigation in so administering the North Platte that seepage accretions from the Federal project and elsewhere are treated as public waters. There has been no court decision interpreting the substitution clause as against an objecting

[31] *Phillip Miller et al.* v. *Peter Wheeler et al.*, 54 Wash. 429, 103 Pac. 641; *Edward J. Breyer* v. *Andrew J. Baker*, 31 Idaho 387, 171 Pac. 1135.

holder of a valid appropriation.[32] The North Platte project management delivers water for Nebraska contractors at the Wyoming-Nebraska State line; the contracts are filed with the State water authorities of Nebraska, and the quantities of water called for by the contracts have been delivered at the contractors' head gates by such authorities without the development of a specific issue as to whether the water in any case was storage, direct flow, or return flow. Default of one of the contracting districts in making payments to the United States, and its claim that storage water was no longer needed in view of the large increase in return flow to the river, threatened to bring the matter of interpretation to a head several years ago, but the case was decided on another point.[33]

Contracts purporting to dispose of return flow discharged into a stream have been held ineffectual for that purpose in Colorado and Wyoming, on the ground that waters returned to the stream after having been used for irrigation or domestic purposes are public waters no longer subject to disposal by the original diverter.[34]

Contracts attempting to dispose of return flow which the project has actually abandoned, or which has been released from control without intention to recapture, are of no effect.[35] The question as to validity of such contracts has been decided in various cases with reference to the intention of the management of the project from which the return waters flowed at the time the return developed. When the waters flowed away there was no intention to recapture. The controlling feature in the Colorado and Wyoming cases cited in the previous paragraph, on the other hand, was that all private ownership in the return waters had ceased; the intention of the parties was therefore of no consequence.

QUALITY AND VALUE OF THE WATER

Drainage water may carry salts in solution of such character and concentration as to make it unfit for irrigation, or at least suitable for crops of high tolerance only. This has proved to be the case on some projects relying largely upon undiluted drainage water. Mixture with water taken directly from the river, on the other hand, has overcome the difficulty. The requirement of the Texas Board of Water Engineers that Lower Rio Grande Valley projects seeking to appropriate drainage water shall also acquire rights to river-flood water gives the project not only a supplemental direct-flow supply,

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[32] Drainage waters which were being substituted under the terms of a Warren Act contract were involved in *United States* v. *Ramshorn Ditch Co. et al.*, 254 Fed. 842 and in *Ramshorn Ditch Co.* v. *United States*, 269 Fed. 80. It was there held that the Ramshorn Co. had attempted to establish an appropriation which under the Nebraska statutes was ineffectual; consequently as against this company the United States had the right "to be unmolested in the possession of its ditch, the right-of-way thereto and the diversion structures thereon, and to use or dispose of the flow in such a way as it may desire."

[33] *Bridgeport Irr. Dist.* v. *United States*, 40 Fed. (2d) 827.

[34] *Comstock, State Engineer, et al.* v. *Ramsey*, 55 Colo. 244, 133 Pac. 1107; *Wyoming Hereford Ranch* v. *Hammond Packing Co. et al.*, 33 Wyo. 14, 236 Pac. 764.

[35] A contract purporting to dispose of waste was held invalid in Nevada on the ground that the water had been abandoned, there having been no intention to recapture when the water was turned from control and allowed to find its way to a stream. (*Otto T. Schultz* v. *John P. Sweeny*, 19 Nev. 359, 11 Pac. 253.) In Oregon, where the city of Baker had released surplus water from its reservoir and allowed it to find the general level of the country "with no intention of recapturing or enjoying it", the city had no further interest in the water and could confer no right upon anyone to its use. The court carefully refrained from calling this water "abandoned", in order to avoid confusion with abandonment of a water right, but referred to it as released or waste water. (*F. C. Vaughn* v. *Adam Kolb et al.*, 130 Oreg. 506, 280 Pac. 518.)

but an opportunity to improve the quality of its drainage-water supply. The quality of river water itself may be seriously impaired by the addition of large quantities of drainage water carrying harmful salts in solution. Whether the problem is serious in a given case depends entirely upon local conditions, such as the extent of reuse of the stream, character of the lands irrigated, and availability of flood flows to freshen the main channel.

The value of return flow, in the last analysis, depends primarily upon its effect in accomplishing the production of marketable farm produce. That is a variable quantity from place to place and from season to season. Values arrived at in various ways, however, have been expressed concretely in contracts for disposal of return waters, and elsewhere, and some of these should be noted. For example, in several of the Pecos River contracts compensation was based upon a modification of the neighboring Hagerman Irrigation Co. values. The market value of a Hagerman right at the time in question was $50 to $55 per acre; as the drainage water was required to be pumped from either a drainage ditch or from the river, the capitalized cost of pumping was deducted with a resulting price in several instances of $15 per acre. In other cases in the same general area the price was solely a matter of bargaining. Based upon quantities measured in 1927, several purchases ranged from $250 to more than $1,000 per second-foot.

Where a substitute supply is available, a measure of value is the cost of such substitute supply. In this connection, the value in the Ramshorn case in Nebraska [36] was the subject of court comment; it being stated that the Warren Act contract provided for a price of $5 per acre-foot, "which appears by the evidence to be about $1,000 per second-foot." Similarly, the value of drainage water recovered so extensively on the Wapato project, Washington, may be taken as the value of an equal quantity of stored water which otherwise would have to be purchased (if available) from the Yakima project. The cost of stored water already purchased by the Wapato was estimated—but not yet fixed—in 1931 as $6.50 per acre-foot. The value of a small quantity of seepage return to Stemilt Creek, Wash., exchanged for direct flow, was locally estimated in 1931 as $500 per miner's inch, or $375 per acre, based upon the commercial value of a class 1 water right, the direct effect of irrigation on apple production having given it this value at that time.

Parshall (*22, pp. 19–20*), writing of conditions in 1920, estimated the value of return flow to the lower South Platte as around $3,000 per second-foot. On this basis the return from Kersey to Julesburg, Colo., for the 10 months January to October, was estimated to be worth $2,250,000 to the farmers of that area.

IDENTIFICATION OF RETURN

Identification of the waters returning from a given project, and accurate ascertainment of their quantity, may be difficult or impossible. Visible inflow can be measured, but it does not necessarily consist entirely of return flow from irrigation. Invisible accretions must be ascertained indirectly. Again, granting that 75 percent of

[36] *Ramshorn Ditch Co. v. United States.* See footnote 32.

the inflow is due to irrigation, what part of that proportion is the result of direct flow and what part is from storage waters? This distinction may be important if the ultimate origin of return waters is held to have a bearing upon their ownership. The distinction, if made, will involve a determination of the rate of passage of water through the soil from the time of its application to its appearance as drainage recovery.

Exact determinations may be impossible, but segregations nevertheless may be made which will do substantial justice to all interested parties. The Federal court, in an Idaho case,[37] in determining that a user was entitled to the return waters from certain lands only, adopted a calculation of the amounts based upon drainage areas and a consideration of the natural flow. The practice of stipulating these matters as the result of careful, unbiased studies has been carried out satisfactorily and should serve as a valuable precedent.

It is considerably easier to arrive at satisfactory results where river conditions as they existed prior to the irrigation and drainage development are definitely known. For example, an organization in Idaho which proposed to install a drainage system carefully measured the increment to the stream for a year before the drains were dug, measured it again after construction, and filed on the difference as developed water. This project should occupy a strong position in the event of contest by other rights. The factor used by the Boise watermaster to segregate the quantity of drainage water actually developed by the Ada County districts is admittedly arbitrary, in the absence of satisfactory basic data, and is not acceptable to all parties. Administration of the Snake River between Neeley and Milner Dam, which credits the Minidoka project with its return flow, has been based upon an assumption that under preconstruction conditions the tributary inflow between those points approximately balanced the losses, and that now it is proper to use the flow at Neeley as a basis for dividing waters at Milner. The careful studies of the middle Rio Grande afford a satisfactory basis for future determinations of quantities of water developed there.

PUBLIC VERSUS PRIVATE OWNERSHIP

Academic discussions of the merits of one form or another of the ownership of return waters have appeared from time to time. The matter was considered at several successive meetings of the Association of Western State Engineers, culminating in two committee reports in support of the public-ownership theory and general discussions preponderantly favoring that view.[38] Probably the foremost exponent of private ownership is the United States Bureau of Reclamation, which for some 20 years or more has been carefully asserting the claim of the United States to all seepage and return waters arising on the Federal projects. Considerable additional support is to be found in the West for private ownership, or for at least some modification of the rigid application of the public-ownership theory.[39]

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[37] *United States* v. *Haga et ux.* See footnote 25.

[38] ASSOCIATION OF WESTERN STATE ENGINEERS. PROCEEDINGS OF FIRST ANNUAL CONFERENCE. Salt Lake City, Utah. pp. 120–134, 1928; SECOND ANNUAL CONFERENCE, RENO, NEV., pp. 79–104, 1929; THIRD ANNUAL CONFERENCE, Denver, Colo., pp. 17–41, 1930. [Mimeographed.]

[39] For other discussions pro and con, see (*2, 6, 16, 31, 32, 33*).

CONSIDERATIONS FAVORING PUBLIC OWNERSHIP

The arguments of advocates may be summarized as follows:

REUSE WITHIN PROJECT

It is conceded by many advocates that reuse of return waters within the project on which they arise has legislative and court sanction and is not subject to debate, provided the lands on which the return flow is to be used have the same date of priority as the lands on which the original flow was used. Objection is taken to interception and recovery of these waters after they have left the project.

PUBLIC INTEREST

Development will be retarded if return water may be bartered and sold. It could be held entirely out of reach of someone who needed it and could use it. With growing scarcity of water the fullest development of the supply is needed.

Under public ownership as now generally practiced, return waters generally supply lower river rights and thereby release natural river flow for up-river development and use, which results in the greatest use and reuse of existing water supplies.

To allow new projects all the benefit of their return flow now is to give them a preferential status. Every ditch contributes some return flow; if one is entitled to its reuse, each one should be. This is impossible without upsetting present water supplies and attendant property values.

RIGHTS OF APPROPRIATION

The view of many westerners is that the State (or the public) owns and controls the water. The water user does not own the corpus of the water; he has a right to its beneficial use. The State cannot part with the ownership of the water, but merely grants a right to its use. The appropriator of natural flow has had use of the water prior to the appearance of return flow, which is all that the State ever gave him or had a right to give him. He cannot claim title to the residue and demand tribute for its use from the lower appropriator. On the contrary, when the needs of an original appropriation are satisfied, the excess should return to the stream to be appropriated for use on other lands. This excess water is simply a vehicle for the water used consumptively, and diversion is permitted by the State for that purpose only. An old appropriator with rights continuing only part of the season should benefit by accretions to the stream.

Beneficial use is the basis, measure, and limit of right to the use of water. This does not include sale, trade, or barter of return flow. One who constructs works and diverts water is entitled to its use once; if he has made beneficial use, his right has ceased, for he has received in full what is intended under the law.

To allow drainage projects to use the drained water works an injury to lower appropriators. The reclaimed land needs water during the growing season; and the drainage discharge may be foreign in time and quantity to the natural flow and therefore if

the drainage yield is exchanged for natural flow it may impose a greater burden on the river flow during the irrigation season than existed prior to the drainage.

An appropriator who specifies the point of diversion, place of use, and area to be irrigated, and then attempts to extend the use to other lands, should go through the necessary statutory procedure for an additional appropriation, the priority of which would be that of the application for additional use.

DETAILS OF ADMINISTRATION

Sales of return flow will complicate and hamper the public administration of water supplies. The practice would require identification and determination of quantities from time to time (as return flow is not static) in order that delivery to specific ditches should not injure direct-flow diverters. It would impose a burden of continuous investigational studies upon water officials, and would be fruitful ground for water disputes.

Under public ownership and control, on the contrary, return waters automatically revert to the public supply upon entry to stream channels and are administered as part of the common water supply. It all goes "into the pool." This procedure simplifies distribution of river flow.

CONSIDERATIONS FAVORING PRIVATE OWNERSHIP

The reasons advanced by those favoring this theory are as follows:

EQUITIES INVOLVED

A project providing and recapturing water at great expense is in equity entitled to its use. The portion of water yielded by drains which have cost a great deal of money—and especially that portion reclaimed from evaporation, actually developed—belongs in equity to the agency making the development.

Vested rights to water prior to upstream drainage construction are not deprived of any water they have been receiving if the drained water—particularly the developed drainage—inures to those incurring the cost of drainage. They are therefore not injured.

Lower river users under the public-ownership theory get something for nothing. They pay no part of the cost of upper basin development, but fall heir to an increased water supply as the result of it.

PUBLIC INTEREST

Revenue from disposal of return flow is a legitimate source from which to decrease per acre project costs, and project extension is possible through the use of return flow. New projects should be allowed to predicate their needs upon consumption of return flow as well as upon the original diversion; otherwise their possibilities will be substantially curtailed.

An added incentive to expenditure of money for drainage construction would be the continued control of the drainage yields and the right to make beneficial use of them, through whatever means of diversion may be most practicable.

RIGHTS OF APPROPRIATION

The right of an appropriator is not exhausted by one use of the water. His right includes reuse, provided it is beneficial and does not deprive an earlier priority of any water to which it has been entitled.

The right of an appropriator should be determined by his intention at the time of making the appropriation. If his plans include the recapture and reuse of return waters, that should govern.

The State's duty is to maintain the same conditions on the river as obtained at the time the appropriation was made. To require drainage discharge to go down the stream to benefit an earlier appropriator at a time when he would not have had water under predrainage conditions is to favor him at the expense of someone else.

If return water must be allowed to augment natural flow, it will work to the benefit of riparian-right claimants in riparian States.

DETAILS OF ADMINISTRATION

Losses from storage and direct flow are not matters of direct determination and need not be, for satisfactory compromise loss-programs can be worked out by the supervising State officials.

POLICIES SO FAR ESTABLISHED

The policies of the water administration offices of the several States may be segregated into two groups—those holding strictly to the public-ownership theory, and those recognizing exceptions or deviations in greater or less degree. Some of these policies and their supporting authority have been referred to from time to time, but they are all summarized below for the sake of completeness.

POLICIES FAVORING STRICT PUBLIC OWNERSHIP

The State engineers of Colorado, Wyoming, Nebraska, Nevada, and Utah regard return flow as the property of the public, and their traditional policies have been opposed to contracts purporting to transfer drainage water from one project to another to the detriment of other appropriators.

The Colorado policy is well grounded in a line of State supreme court decisions that are definite and comprehensive. It is considered that after water has been used for the purpose for which it was appropriated and decreed, any unused portion is abandoned to the natural stream into which it would flow if not intercepted, for the enjoyment of all junior appropriators. A different rule applies in case of foreign waters not naturally tributary to the stream toward which they now drain—that is, waters brought from another watershed, or from an enclosed basin in the same watershed.

The Wyoming State engineer considers return-flow water subject to reuse by other appropriators immediately upon its return to the stream, and not subject to appropriation by others before it has returned to the stream. The basis of this policy is a decision of the State supreme court in a case in which the return (sewage) had been discharged into the stream from which diverted.[40] There is no

[40] *Wyoming Hereford Ranch* v. *Hammond Packing Co. et al.* See footnote 34.

decision as far as could be ascertained, concerning the status of return waters en route from the project boundary to the stream. The right of a Federal project to recapture and reuse its own return flow within its boundaries has been upheld by the United States Supreme Court.[41]

The Nebraska Bureau of Irrigation, Water Power and Drainage considers return waters as public waters on leaving the project for which the original appropriation was made. There are no Nebraska State Supreme Court decisions on this matter. A Federal circuit court decision [42] upholding the right of a Federal project—as against a company which was attempting to establish an ineffectual appropriation—to recapture seepage water on its way to the North Platte and to deliver it to a Warren Act contractor in lieu of storage or direct flow, is not regarded by the State officials as setting a final precedent for State administrative policy in regard to the general question (*17, pp. 301–304*).

The Nevada and Utah policies have developed without court decisions concerning the right of a project to dispose of return flow which it had not abandoned. The streams of both States (with one exception noted in the adjudication of Provo River, Utah) have been administered without reference to the origin of return flow and apparently with few or no resulting controversies.

POLICIES RECOGNIZING SOME RIGHTS OF RECAPTURE

The administrative policies of the other States are generally to consider return flow in a stream as a part of the public waters of that stream, but some of them have given official recognition to cases of recapture or substitution of return waters or of disposal before reaching a stream channel.

The New Mexico State engineer approves applications to appropriate drainage waters turned into a stream with the intention of subsequent appropriation and recapture. The application may be made by the project yielding the drainage water, or by another who has contracted for the use of that water. A statute authorizes the appropriation of seepage from constructed works. Water flowing in an artificial drain is not subject to appropriation by others, but the creator of the flow has control until it has been deposited in a natural stream.[43] Most of the drainage water involved in applications to appropriate has originated in artesian sources not naturally tributary to the flow of the stream into which the drainage has been diverted. Conservation districts developing or reclaiming water are given statutory authority to make beneficial use of it.

The Texas Board of Water Engineers regards drainage waters accumulated in artificial channels as under the control of the person or corporation responsible for the accumulation, and authorizes appropriations of such waters by others only if they have made contracts for its diversion and use with the one who accumulated the waters. All such cases to date have been in a delta region in which the water would not have returned naturally to the stream from which diverted. Drainage waters that have found their way into a

[41] *Ide et al.* v. *United States.* See footnote 24.
[42] *Ramshorn Ditch Co.* v. *United States.* See footnote 32.
[43] *Hagerman Irr. Co.* v. *East Grand Plains Drainage District,* 25 N. Mex. 649, 187 Pac. 555.

natural channel are considered as being on the same basis as other waters in that channel.

The Washington Department of Conservation and Development until recently recognized the right of the owner of a tract, on which measurable drainage or return seepage from irrigation arose, to divert from the stream into which discharged a quantity of water equivalent to the quantity released. The authority was a case in which the decision approved this method of substitution, but in which the right to make use of the seepage water was not in controversy.[44] Substitution was allowed in addition to the original diversion only to the extent of beneficial use; that is, where the original priority was not such as to afford an adequate water supply. Recently, however, the department has reversed its policy, owing to abuses of the privilege and resulting confusion and protests from lower users. Exchanges not previously authorized are not now being permitted. The present policy is to consider return seepage as a part of the stream supply.

The Oregon State engineer considers in general that seepage waters in a stream are public water. However, the State engineer on the authority of an Idaho decision [45] (there being no Oregon decisions in point) authorized the upstream diversion of water equivalent to the amount of drainage discharge in preference to its use by a lower prior appropriator in a case in which the waters had been stored and brought from another drainage area, and in which the upstream right was inadequate. In another instance a contract was recognized in which one project exchanged reservoir space and direct-flow rights for equivalent return flow from another project. Reuse of water on a project on which originally applied may be made without permit from the State, as it is covered by the original appropriation. Permits to appropriate seepage water within the boundaries of an irrigation district, made by others than the district itself, will not be granted without a release by the board of directors of such district.

The Idaho Department of Reclamation grants permits to appropriate the unappropriated waters of the State, without authority to place limitations or restrictions upon the applicant, but does not issue permits upon drainage or waste water as such. However, permits are issued under the authority of a specific statute to drainage districts for the use of the drainage water appearing in their ditches. In some cases these waters are diverted directly from drainage ditches into irrigation channels; in others mingled with the river waters and rediverted; and in still others discharged into the river and an equivalent amount diverted above the point of discharge.

The California State Division of Water Resources regards return waters from power use, after having been stored, as foreign in time to the natural stream flow and, therefore, not water which inures to the benefit of prior appropriators or riparian owners.

In Arizona a project has the right, at least as against a shareholder, to dispose of its drainage waters for compensation outside the project.[46] In the case establishing this point, the rights of lower diverters, whose water supplies might be affected by the interception

[44] *The State of Washington* v. *American Fruit Growers, Incorporated et al.* See footnote 27.
[45] *Breyer* v. *Baker.* See footnote 31.
[46] *Brewster* v. *Salt River Valley Water Users Association.* See footnote 19.

of return flow, were not involved. Drainage waters captured by a drainage district may be disposed of by sale or contract and are not subject to appropriation by others.[47]

There is no administrative authority in Montana over the acquisition of water rights and the distribution of water. Waste waters may be appropriated,[48] but no cases are known passing upon the right of a project to dispose of its waste waters for compensation. In fact, a Federal case [49] denied the right of an appropriator to exceed his decreed right on the justification that the resulting seepage benefited lower prior appropriators, who were held to be entitled to the natural flow plus the seepage from his lands.

GENERAL ABSENCE OF JUDICIAL PRECEDENTS

In very few States are there court decisions clearly and specifically defining the right to recapture return flow after it has commingled with the direct flow of a stream, where such action involves no question of abandonment but is part of a definite plan of development; or the project's right to dispose of its drainage waters to others where lower appropriators otherwise would make use of it. Colorado is the outstanding exception; there the question has been comprehensively litigated. Except in Colorado the court decisions, where any have been rendered, have usually involved one or two points only and have left other phases of the question unsettled. The courts ordinarily do not pass upon matters not necessary to be decided in settling the main points at issue in a suit. Where they do comment on questions which need not be decided, their remarks are not necessarily controlling as precedents in later actions.

Likewise, there is very little statutory direction to the State administrative officers in distributing return flow. In most of the States the general principle has been accepted—either tacitly or directly in decisions on controverted points—that return waters are a part of the natural river flow. Nevertheless in some jurisdictions it has seemed best to modify the principle where there is no question of abandonment of waste water.

IMPORTANCE OF A WELL-SUPPORTED POLICY

The lack of judicial precedent and support in so many States leaves doubt as to the stability of some of the prevailing administrative policies, and as to the status of return waters now being distributed in accordance with them. Vested rights will have protection, naturally; but just what are vested rights to return waters? Does the appropriator of water have a vested right to the return flow from all upstream diversions, or do the upstream projects have vested rights to their own return flow? And what of return flow that has not yet become evident, but which in the light of past experience may be expected to appear in a given locality sooner or later? Who may claim that? These questions cannot now be answered with certainty in several of the western jurisdictions; but controversies over them in various localities can be predicted with reasonable certainty.

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[47] *Wattson et al.* v. *United States*, 260 Fed. 506.
[48] *Popham* v. *Holloron*, 84 Mont. 442, 275 Pac. 1099; *Newton* v. *Weiler*, 87 Mont. 164, 286 Pac. 133.
[49] *Marks* v. *Hilger*, 262 Fed. 302.

THE SITUATION WITH REFERENCE TO FEDERAL PROJECTS

A member of the staff of the Department of Justice who has been engaged in numerous water-right cases has worked up considerable material to support the thesis that "the United States is the owner of the unappropriated waters in the nonnavigable streams in the public land States of the arid West."[50] This is what is known as the "reservation theory"—that the United States has never granted the waters to any of those States, and that the unappropriated waters still belong to the United States, consequently that so much of the unappropriated waters as may be needed for irrigation uses upon an Indian reservation or a Federal reclamation project may be reserved from further appropriation.

Opponents of this thesis point to the Reclamation Act of 1902—which directs the Secretary of the Interior in carrying out the provisions of the act to proceed in conformity with State and Territorial laws relating to the appropriation and use of water—as settling whatever doubt might otherwise have existed that the United States must secure its appropriations of water for Federal reclamation projects from the States.

Claims to reuse of seepage waters on Federal projects have been upheld in several Federal court decisions, one by the United States Supreme Court;[51] but these decisions have not been based upon outright ownership on the part of the United States. There has been nothing yet in the Federal decisions concerning return waters, so far as ascertained, that definitely distinguishes the right to their use by the United States from the right of a private appropriator from whose project return waters flow. In no case which has come to the author's attention has the right of a Federal project to redivert its return waters from the main stream channel and to deliver them to an independent user for compensation been brought up for determination.

In conformity with the Reclamation Act, applications have been made consistently to the several State authorities covering appropriations of water for Federal projects. Many of the projects cover large areas, and the appropriations have been extensive. The original application for an appropriation to the Nebraska authorities in connection with the North Platte project, for example, was made for the irrigation of "all the irrigable lands on the north side of the North Platte River." This was held in the *Ramshorn case*[52] to cover the lands of Farmers' Irrigation District, so that the reclamation project in delivering drainage waters to the district was entitled to the benefits of a statute then in force authorizing the owner of an irrigation canal to collect seepage water thereunder to apply to the irrigation of land covered by the original appropriation. The significance of this is that the Farmers' District appropriation is prior to that of the Federal project, yet the latter appropriation was held to embrace the Farmers' lands so far as this particular statute was concerned.

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[50] WARD, E. MEMORANDUM, FEDERAL IRRIGATION WATER RIGHTS. 17 p. Denver, Colo. 1930. [Manuscript.]

[51] *Ramshorn Ditch Co.* v. *United States; United States* v. *Haga et ux.*; and *Ide et al.* v. *United States.* See footnotes 32, 25, and 24, respectively.

[52] *Ramshorn Ditch Co.* v. *United States.* See footnote 32.

Various State statutes have been passed to facilitate Federal reclamation, definitely providing for the use of water on Federal projects and giving them certain privileges not granted generally in case of initiation of private appropriations. For example, New Mexico, North Dakota, Oklahoma, Oregon, and Washington provided for the withdrawal of waters from appropriation for periods of years for the benefit of the United States in connection with projects under consideration; Montana provided that appropriations by the United States should be held valid for 3 years without commencement of construction; Nebraska authorized the execution of contracts for rental or sale of "developed, stored, flood, or unused water" in excess of project requirements, from the United States to persons holding permits to appropriate normal flow which shall have proven insufficient for their needs.

The assertion of claim of the United States to all return waters arising on Federal reclamation projects is of long standing. It appeared in the annual report of the Reclamation Service for 1912–13 (*20*) in connection with the statement of the irrigation plan of each of the reclamation projects, and was consistently reasserted in subsequent reports year after year. The wording in the majority of cases was: "The United States claims all waste, seepage, spring, and percolating water arising within the project and proposes to use such water in connection therewith." The published maps of the projects bear the same wording. The claim of the reclamation projects to their return waters has been asserted in several court actions.

It appears, then, that the Bureau of Reclamation has been diligent in asserting and maintaining the right of the Federal projects to recapture and reuse return waters arising on such projects. The Federal decisions leave no doubt as to the view of the courts that there has been no abandonment of these waters by the United States; and the right to recapture and reuse these waters on project lands before they have escaped from the project is apparently well established. The right of a Federal project in Idaho to mingle return waters with the direct flow of a stream and later to redivert them was stated in a Federal decision in that State, the case not having gone to the United States Supreme Court. It further appears that neither Federal nor State courts have ruled specifically that return waters from Federal projects are subject to different rules of law from those governing the return from private projects.

AN EQUITABLE POLICY LEADING TO EFFICIENT STREAM UTILIZATION

In stating what in effect are the conclusions reached from this study, it is appreciated that laws and court decisions differ and that a policy which may have sound legal foundation in one State may be out of the question in another. No criticism is intended of any established policy or of the legal authority on which it rests. These decisions invariably have been carefully considered. The purpose of this section is to state what appear to be equitable principles concerning rights to the use of return flow in jurisdictions in which the constitutions and laws are such that the principles may be applied.

Specifically, the law in certain jurisdictions is such that return water immediately upon entering the stream from which diverted

becomes public water, regardless of human intentions. Every appropriator is on notice that that is the law; for one to recapture return flow to which he has no title is not only illegal but is inequitable, for the use belongs to others and the fact is known. That, however, is not the established law everywhere. Where it has not become established, principles which do involve the recapture of return flow under certain circumstances may be entirely equitable.

It is generally considered that return flow may be recaptured before it leaves a project and reused upon the lands of that project, regardless of possible uses elsewhere. If this is equitable, it follows that a user elsewhere is being deprived of water to no greater extent if this return flow, instead of being recaptured before it reaches an arbitrary boundary, is allowed to cross that boundary or even to mingle with the stream waters. The sticking point in certain jurisdictions is a matter of law, and not necessarily a consideration of equity to possible users elsewhere.

RETURN FLOW IN RELATION TO BENEFICIAL USE

Beneficial use, unless the statutes and court decisions require it, is not necessarily exhausted by one application of irrigation water. Recapture and reapplication of the same water may satisfy all requirements of beneficial and economical use from a physical standpoint. The process of picking up and reusing one's own waste water is one form of distribution of the original supply. Whether water is allowed to escape from an earthen ditch by seepage and later recovered and taken into another irrigation ditch, or is carried across a project in a cement conduit, is a matter of management, so long as lands which are not concerned with the project plans are not injuriously affected. If beneficial use results in the long run, the rights of the public are satisfied. And in a case in which the project lands respond readily to drainage, the question as to whether the canals shall be lined or a drainage recovery system installed may be a matter of internal economics for the management of the project to decide, rather than a question of beneficial use under the original appropriation.

Some so-called waste is unavoidable. It is impracticable, except possibly in a few extreme instances, for a project to deliver to the farms 100 percent of the water diverted, and impossible for the plants to consume 100 percent of the water applied. If the irrigation practice is reasonable, there appears to be no reason why a project should not be permitted to reuse its waste waters where it can do so to advantage, and where there is no resulting injury to other appropriators. A different question is presented—and one which is outside the scope of the present discussion—where use is wasteful and the excess is lost by evaporation or otherwise and there is consequently no return flow to compensate other appropriators.

RETURN FLOW IN RELATION TO RIGHTS OF OTHER APPROPRIATORS

The doctrine of prior appropriation governs the use of water on most of the irrigated land in the West. Public policy is served by protecting appropriators of water in their right to continued use of the water appropriated, so far as it is available, in the order of their

priorities. This is a fundamental principle. Each intending appropriator when he goes upon a stream initiates his right subject to all existing appropriations, whether already perfected by application to beneficial use or in process of being perfected. He takes things as he then finds them. His potential right attaches to a portion of the water then unappropriated, at such times as it may become available in the stream. And the right that he then initiates and perfects is prior to that of every later or junior appropriator, who in turn takes his place in line just as his predecessors did.

The right to make use of water is a relative right. An appropriator is under obligations to all other users from the same source of supply. His right must be exercised with respect to all appropriations both senior and junior to his own.

It would appear, in regulating the diversion of a project from which return water is flowing, at a time when the natural river flow is not enough to supply all priorities, that:

(1) There is no material injury to an appropriator with priority earlier than that of the project in question, if the stream conditions affecting the earlier diversion are maintained substantially as they were when the earlier appropriation was made; in other words, before any junior rights had been initiated. There is no injury if the quantity of water at this earlier appropriator's head gate is just what it would have been had there appeared no subsequent appropriators.

(2) There is no material injury to an appropriator with priority junior to that of the project in question, if the utmost beneficial use is being made of a senior appropriation on the lands covered thereby, according to the terms of such senior appropriation at the time the junior appropriation was made.

EFFECT UPON EARLIER APPROPRIATOR

If the first principle is equitable, it follows that a junior appropriator who can so manage his junior diversion as to reuse the return water on his own lands, or even on other lands, without depriving the lower senior appropriator of whatever quantity of water would have flowed down to his head gate but for the junior diversion, is working no injury to the senior appropriator. He is diverting water under his appropriation only when there is enough for both the senior appropriator and himself, and whether he applies the water carefully or lavishly, the rate of his diversion at such time does not deprive the senior of any water to which the latter is entitled at that time. When the river supply falls, the junior diversion is promptly cut in favor of the senior.

Specifically, if A has a right to divert 25 second-feet, and B, with head gate next above on the stream, has a later right, and at the time of A's appropriation there was neither gain nor loss between diversion points B and A—then, when the stream at B drops to 20 second-feet, A's water supply is short by 5 second-feet as the result of natural forces. If in the meantime, as the result of B's use of early season water, local stream conditions are so changed that there is a flow of 5 second-feet from B's lands above A's diversion point, which would give A his full appropriation right if he were to divert it, but which B can redivert and put to beneficial use, the conditions affecting A's appropriation at the time he initiated it are in no way altered if B

does recapture this water. A would have only 20 second-feet—not 25—if B had never appeared. Furthermore, so far as injury to A's appropriation is concerned, it makes no difference whether the 5 second-feet is intercepted by B before it reaches the stream, or is substituted at B's head gate, or is rediverted by B from the stream either above or below A's head gate. Unquestionably the point of diversion makes a great difference legally in some States; but in jurisdictions in which there is no legal injury to A, it is difficult to see wherein the physical injury lies, provided, of course, the return flow has been recaptured immediately by B before giving A reason to rely upon its use. A practical difficulty in regulating the diversions lies in the necessary measurements of flow; but such measurements have been made and can continue to be made. Stream distribution is not a simple proceeding under even the happiest circumstances.

EFFECT UPON THE JUNIOR APPROPRIATOR

The junior appropriator is entitled in law and in equity to have the stream conditions maintained as they were when he initiated his appropriation, and to suffer no enlargement of prior rights which will adversely affect his own. The junior appropriator, upon initiating his right, is charged with notice of all rights prior to his own, and of the areas of land covered by such rights in jurisdictions in which water is appurtenant to land, and (at least theoretically) predicates his development upon the use of a portion of what is left of the river supply after the quantities allocated to prior rights have been put to beneficial use upon those lands. As long as prior rights, as they existed when the junior appropriation was made, are not enlarged by excessive diversions of water or by inclusion of additional lands, the junior appropriator is not injured.

If the previous specific example is altered by making A the junior appropriator, and B the senior upstream appropriator with a right to use 25 second-feet on a given tract of, say, 1,750 acres, A is not injured if B recaptures and reuses beneficially his return flow of 5 second-feet on that tract of 1,750 acres, or on an equivalent area to which the appropriation has been properly transferred. No enlargement of B's right is taking place. The stream conditions above B's head gate are unchanged, and he is taking no more than his allotted 25 second-feet of the water reaching his head gate and is using it on only that 1,750-acre tract or its equivalent. B's use is within his appropriation, and if it is beneficial, A is not being deprived of any water which was unappropriated at the time he initiated his own right. Furthermore, so far as injury to A is concerned, the point at which B diverts the return flow is immaterial. This is on the assumption that B recaptures his return flow promptly, before A has reason to start building a development upon its use.

It follows from this that A is materially injured if B uses his 5 second-feet of return flow on lands in addition to the area covered by his prior appropriation, in jurisdictions in which the appropriation is tied to a specific tract or area of land or to a project with designated boundaries. This is an enlargement of B's right as it existed when A's right was initiated. It is an alteration of the terms of A's contract with prior appropriators, without his consent. Whether B's proposed use of the return flow on the additional

lands is beneficial or not is beside the point. B contracted to make beneficial use of 25 second-feet of river flow on 1,750 acres; and any part of that 25 second-feet not required for that purpose is outside of his contract and inures to the benefit of junior appropriators who need it. Delivery of the 5 second-feet of return flow, arising on the 1,750 acres, to additional land is essentially the delivery of part of the original 25 second-feet to additional land, insofar as the junior appropriator is concerned; for if the requirements of the original tract are satisfied by this original 25 second-feet alone, the return flow can be reapplied, if convenient, to the 1,750-acre tract and an equivalent quantity released at the head gate for the junior appropriator, or else the return flow itself allowed to go down.

It also follows that in jurisdictions in which water is not appurtenant to land by law and an appropriation is not limited to a definite tract or area of land, A is not injured by B's use of his own return flow on lands other than those on which the return arises. Here the limitation upon the appropriation of 25 second-feet is beneficial use upon land. It is the quantity of river flow which B may take at his head gate that A looks to when he initiates his own right. If B can so distribute his 25 second-feet as to cover 2,500 acres beneficially, instead of 1,750 as his neighbors may be doing, A cannot complain. Likewise, if B may intercept his own return flow and reapply it beneficially, or redivert it from the river, A is not being deprived of any water which was in the contract when he initiated his own subsequent appropriation.

EFFECT UPON INTERVENING DIVERTER

An appropriator is entitled to have his just share of the water supply delivered at his head gate, regardless of the convenience of earlier or later appropriators. This means that the substitution of water at one's head gate, if allowed at all, must be made so that the intervening diverter is not deprived of any part of his supply. To take 5 second-feet of water at one's head gate in place of an equivalent quantity of return flow discharged into the stream below another's head gate is inequitable and illegal if the intervenor needs that 5 second-feet to fill out his quota.

RETURN FLOW UPON WHICH OTHER USERS HAVE DEPENDED

Regardless of the equitable right of a user to recapture his own return flow, a difficult question is presented where the return has been allowed to find its way back to the stream and other appropriators have been expending money and labor in the development of land and putting this water to beneficial use on the assumption that the supply would continue.

A water user is under no obligation to continue wasting water, and can so alter his irrigation practice that there shall be a minimum of waste. This is a well-established principle. Beneficiaries of the waste take on sufferance only. An interception and beneficial reuse of the return flow on the lands for which the original appropriation was made is essentially within this principle. If the user for this purpose may intercept his return water before it reaches the stream,

there is no equitable reason why he should not recapture it after it is in the stream (in those jurisdictions in which the legal right to do this is sound), provided the quantity and quality of the stream water remain substantially unaltered.

The equitable rights of others who in the meantime have been making beneficial use of this return water, and who are deprived of a valuable supply by the original user's recapture, would seem to depend upon the matter of diligence of the original user in perfecting his appropriation. If he has been diligent in putting his original supply and the return-water supply to beneficial use according to the terms of his original appropriation, other users then have full notice of the situation, and they are proceeding at their own risk if they build development upon the assumption that the discharge of return waters will continue. If, on the contrary, the original user is not diligent, the State is justified in canceling through statutory procedure that part of the appropriation that has not been put to beneficial use according to the terms on which it was initiated. Other appropriators who themselves have been making use of the return water will automatically benefit.

Extension of the area covered by the original appropriation, as a result of recapture of return water which others have been using beneficially, deprives these others of a supply to which they have become equitably entitled. Whether they have made new appropriations based upon the increased stream supply, or whether the water simply fills out their existing appropriations, does not affect the situation. As appropriators they are entitled to have other appropriations held to the terms on which initiated.

A different situation is presented where for years and decades numerous rights have been established upon a stream and the return waters have been distributed as a part of the common supply without question. A custom has been built up, the stream characteristics have been changed substantially as a result of the established practice, and all comers take with knowledge of such conditions. Here, to introduce the right of appropriators generally to recapture return flow which invariably and completely has been going into the general supply would be to disrupt the physical situation and to lead to impairment or destruction of rights predicated upon an established custom, and therefore would not be in the public interest.

However, existing equities on such a stream would not be disturbed in any manner by allowing a new appropriator, from whose lands there has yet been no return flow, to plan his development upon complete utilization of his late appropriation and of all return waters realized from it. No one, in such case, is injured, and no one is being misled. Nor need the custom established upon this stream control the distribution upon another stream where rights have not become similarly established, if it proves that a different custom may result in the greatest beneficial use.

UTILIZATION OF RETURN FLOW IN RELATION TO PLANS OF DEVELOPMENT

WHERE NOT PART OF ORIGINAL PLAN

The original plans of probably most projects on which return flow in substantial quantities has appeared did not contemplate its reuse. There was apparently no general appreciation on the part of or-

ganizers that this would be an important result of development, although problems of drainage disposal were constantly arising. When these waters do appear in sufficient volume to attract attention, it is probably natural that the project on which they arise should seek to benefit from them, either by making direct use or by securing revenue from other users, particularly in view of the growing scarcity of available water supplies and resulting higher costs of irrigation development. Consequently many controversies over this question have arisen as the result of subsequent rather than original plans of utilization, and they are correspondingly difficult to settle with equity to all concerned.

Where the return waters have been allowed to go down the stream season after season and others have been making use of them and have built development on the assumption that they were a part of the natural stream flow, and the upper project has done nothing to prevent, then to allow it as an afterthought to demand compensation from such users or to contract these waters elsewhere to third parties appears inequitable.

On the other hand, even if the waters have been going down the stream for long periods, but before anyone else has made use of them, the upper project makes its plans to use the waters elsewhere and takes the necessary legal and physical steps to carry out such plans, then it would seem to make no difference whether the waters are used on new project lands or contracted to other projects or rediverted by the original project at its own head gate. No other appropriator is being deprived of a water supply which existed when he made his appropriation, or is being deprived of a supplemental supply of which he has been making beneficial use. The first use of these return waters then becomes a matter of new appropriation, if applied on lands other than those on which the original appropriation was made. In such case, if made by B (a lower user) rather than by A on whose lands the return arises, any contract between A and B is simply an assurance to B that A will not reuse these waters on lands covered by A's original appropriation. Whether B makes an appropriation of the water after it is in the stream, without regard to A's possible plans, and before A has taken steps to appropriate it himself for use on additional lands, or whether B at the same time protects himself against A and all others by making a contract with A, would seem to be a matter entirely between these two. The interest of the State is in seeing that the first appropriator gets the water.

WHERE PART OF ORIGINAL PLAN

Inclusion of plans for utilization of waste waters as part of the original scheme of development simplifies matters considerably. No one is misled or has any excuse for being misled. No existing development is impaired; no one is deprived of water which, under the stream conditions as they existed when he made his appropriation, he would have been entitled to use but for the present plan; and interposition of subsequent uses is not involved. This is on the assumption that the terms of the appropriation are clear and that the plans of development are carried out diligently.

The appropriation is made for a specific quantity (or flow) of water from the natural flow of the stream, which, together with all

return waters resulting from its use, will be applied on a given area of land or on so much of that area as can be beneficially and economically irrigated. It should make no difference to prior appropriators whether that area is a contiguous body of land or consists of two or more parcels many miles apart, as long as the stream conditions are maintained as they would have been had the new development not taken place. And all subsequent appropriators are apprised of the extent of use which is proposed to be made of the appropriation in point.

RETURN FLOW IN RELATION TO EFFICIENT STREAM UTILIZATION

Any policy governing the ownership of return waters which encourages wasteful irrigation practice is, of course, contrary to the public interest. A wasteful practice is essentially one which involves unnecessary diversion of water which others could and would use if it were available. It involves the squandering or destruction of a resource. Diversion and application, however lavish, of an ample stream of water which others do not need and which cannot be stored in reservoirs for later use is not wasteful where it does not deplete any of the State's natural resources or injure good lands unnecessarily through excessive seepage. An appropriator who follows the practice of storing large quantities of water in his soil when the river is in flood, with a view to recovery and reuse of the drainage waters when the river stage is such that he has no right to divert directly, may be making the highest beneficial use of his water supply. This is on the assumption that his action does not result in injury to valuable farm lands, whether owned by himself or by others.

A head-gate diversion at a time when junior appropriators are in need, that permits an application of water so lavish as to yield a substantial return flow, is not equitable to the junior appropriators, even if the recorded rights of the senior are not exceeded. Proper utilization of the stream would require a reduction of the head-gate diversion to an amount which would give this senior diverter what he needs, with due regard to soil and crop conditions, and with the least practicable waste, so that during this period of shortage other lower users could be supplied directly from the stream without the lag occasioned by transportation of excessive quantities of water through the soil. If the return flow in question has been appropriated by the original diverter for use on other lands with the same priority, then the question as to whether he reduces his head-gate diversion and takes out the difference below, or leaves the head gate open at the maximum point and recaptures the return flow later, is a matter of local management for him to decide, provided, of course, whatever practice he adopts results in beneficial use and does not affect the diversions at intermediate head gates.

Plans of a late appropriator to recapture and reuse the resulting return flow would seem to be in line with efficient stream utilization. In fact, that is the only way in which further development can take place on many streams. It is a common occurrence to find the usual summer flows of streams fully appropriated, sometimes several times over, yet to find these same streams yielding spring-flood flows beyond the requirements of existing appropriators. To take a modi-

cum of spring flow, store part of it in a reservoir if possible, apply it to the soil and recapture the drainage for further application, and construct a project on the basis of complete utilization of that modicum, requires a degree of care in plan and execution that leaves no room for wasteful practice at any point. The incentive is to use that water carefully and efficiently.

Whether the best use of present unappropriated flood flows of a given stream would be served by permitting the reuse of return waters as above outlined, or by requiring the return to go down the stream to enrich existing priorities and improve the character of development already in existence, depends upon the local circumstances in each case. Diversion of flood flows for new early season use and larger later season flows for existing projects as a result of the upstream diversion may be the better economics on some streams. In other cases it may prove best to restrict existing areas and concentrate on the new areas. Granted that in a given case the new development is desirable, either in addition to or in substitution for an existing project, efficient use of the spring flood involves the careful reuse of return waters.

CONCLUSIONS AS TO EQUITABLE POLICY

Where the law has been settled to the effect that return waters, upon leaving the project on which they arise, or upon reentering the stream from which diverted, are immediately transformed into public waters, it is not only illegal but is inequitable to other appropriators for a project to recapture its return flow after such transformation of character has taken place. On the contrary, in jurisdictions in which the law has not become established to such effect, it is not inequitable to allow a project the beneficial reuse of its return waters, provided all other appropriators are fully protected in all rights theretofore acquired. In such jurisdictions a lower user who has acquired neither legal nor equitable title to the use of return flow arising on an upper project is being deprived of water to no greater extent if the return is recaptured after leaving the upper project than he is where the return is recaptured before leaving the upper project boundaries.

It is inequitable for a project to intercept or recapture its return flow to the injury of other appropriators, either senior or junior. Senior appropriators are entitled to have the stream conditions maintained as they were when their appropriations were initiated, and are injured to whatever extent reuse of return flow by others interferes with this right. Junior appropriators are injured if reuse of return flow by an earlier appropriator works an enlargement of the earlier appropriation. Appropriators whose head gates are located between the point of original diversion of another project and the point at which its return waters reenter the stream are injured by any rediversion at the other project's head gate, in substitution for an equivalent of return flow, that cuts short the quantity they are entitled to receive.

Beneficial use of water is achieved by a project which plans and carries out diligently a complete utilization of both its original diversion and its return flow, where this can be accomplished (1) without depriving prior appropriators of any water supply which would

have been available to them but for the later use, (2) without enlarging upon its appropriation to the detriment of later appropriators, and (3) without depriving others of a return water supply which they have been allowed or encouraged to use and which they have had reason to think would continue. This is accomplished most satisfactorily if the reuse of return flow is indicated in the original appropriation; but it can be covered effectively by a later supplemental appropriation, provided the rights of others who in the meantime have initiated appropriations are properly safeguarded.

Introduction of a policy of permitting users to recapture return flow which they have always allowed to escape, and which for years has been consistently administered as public water, and on the strength of which development has taken place, would completely upset existing equitable rights so built up and would be contrary to the public interest. However, new development upon even such a stream, predicated upon consumptive use and involving the beneficial use of return waters which have not yet appeared but which may be reasonably expected to appear, would not disturb existing rights; and if the new development is justified, would be in the interest of efficient stream utilization.

SUMMARY

Return flow from irrigation includes both avoidable and unavoidable losses from the irrigation project. Normally, but not necessarily, it returns to the stream from which diverted. Visible return flow is that portion of the return water which appears at the ground surface before reaching the stream, whereas invisible return flow enters the stream channel below the water surface. Visible return flow is often directly measurable.

Observations concerning the relation between seepage from irrigated lands and increases in river flow were made by the State engineer of Colorado 50 years ago. In following years the phenomenon aroused interest and study in a number of Western States; recognition is now widespread throughout the West. Accretions to water supplies from this source, which are to be noted along most streams within or below irrigated valleys, make it possible to irrigate much larger areas from many streams than was formerly thought practicable. It is not uncommon to find the entire flow of a stream diverted at a certain head gate throughout a period during which return flow into the stream below the head gate is supplying the needs of extensive irrigated areas.

Numerous conflicts have arisen over the possession of return waters, with the cleavage principally between public and private ownership. Under the public-ownership theory, return waters are not the property of the project from which they flow, but become a part of the stream system available to appropriators in order of priority; under the private-ownership theory, they are at the disposal of the project on which they arise. The courts in certain States have ruled as to whether return waters are public or private property, while in others the general question has not yet been settled; and, except in Colorado, the many angles to the return-flow question have not been comprehensively litigated. In many sections of the West extensive development has taken place with water rights

predicated wholly or partly upon return flow. There is no uniformity among western jurisdictions as to the right to recapture or appropriate return waters from irrigation, or as to the point at which they may be recaptured; and prevailing practices in various important places are as yet without judicial sanction.

The policies of the water administration offices of the several States may be divided into two groups: (1) The State engineers of Colorado, Wyoming, Nebraska, Nevada, and Utah regard return flow as the property of the public, and their traditional policies have been opposed to contracts purporting to transfer drainage water from one project to another to the detriment of other appropriators. (2) The other State engineers generally consider return flow in a stream as a part of the public waters of that stream, but some of them have given official recognition to cases of recapture or substitution of return waters or of disposal of the same before reaching a stream channel. There is very little statutory direction to the State engineers in distributing return flow. Furthermore, the lack of judicial precedent and support in so many States leaves doubt as to the stability of some of the prevailing administrative policies and as to the status of return waters now being distributed in accordance with them.

There has been considerable controversy as to the right of the United States to recapture and reuse the waste and seepage waters arising on Federal projects. The Federal decisions leave no doubt as to the view of the courts that there has been no abandonment of these waters by the United States; and the right to recapture and reuse these waters on project lands before they have escaped from the project is apparently well established. Neither Federal nor State courts have ruled specifically that return waters from Federal projects are subject to different rules of law from those governing the return from private projects.

Equitable principles concerning rights to the use of return flow, in jurisdictions in which the constitutions and laws are such that the principles may be applied, are as follows: (1) Where the law has been settled that return waters become transformed into public waters, it is not only illegal but is inequitable to other appropriators for a project to recapture its return flow after such transformation of character has taken place. Where the law has not been so established it is not inequitable to allow a project the beneficial reuse of its return waters, provided all other appropriators are fully protected in all rights theretofore acquired. (2) It is inequitable for a project to intercept or recapture its return flow to the injury of other appropriators, either senior or junior. (3) Beneficial use of water is achieved by a project which plans and carries out diligently a complete utilization of both its original diversion and its return flow, where this can be accomplished without injuring either prior or later appropriators and without depriving others of a return water supply which they have been allowed or encouraged to use and which they have had reason to think would continue. (4) Innovations which would upset long-established practices on a stream, on the strength of which development has taken place and that would injure equitable rights predicated upon such practices, would be contrary to the public interest. New development upon such a

stream, based upon consumptive use and involving the beneficial use of return waters yet to appear, should not disturb existing rights; and if the new development is justified, would be in the interest of efficient stream utilization.

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THE EFFECT OF HOMOGENIZATION ON CERTAIN CHARACTERISTICS OF MILK

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INTRODUCTION

During the past few years homogenized milk and cream have received considerable attention from research workers. The work of Hill (*7*, *8*, *9*),[1] Espe and Dye (*5*), and others on soft-curd milk and its relation to digestibility, together with the work of Washburn and Jones (*18*), Washburn (*16*, *17*), and others showing the possibility of producing soft-curd milk with the homogenizer, is bringing homogenized milk to the attention of milk dealers as well as research workers. In addition to its soft-curd properties homogenized milk has other advantages. For example, Kelly (*13*) has shown that serving homogenized milk to school children insures that they are not deprived of a proportion of the butterfat which they are supposed to receive. That homogenized milk has commercial possibilities has already been demonstrated in sections of Canada, where some dealers homogenize the greater proportion of their market milk. The milk consumers of the United States have associated cream line with quality for so long that undoubtedly it will be many years before the practice of homogenizing market milk becomes general. It can be safely predicted, however, that the practice will gradually be extended.

[1] Italic numbers in parentheses refer to Literature Cited, p. 11.

Before entering the field of distributing homogenized milk there are several questions which the milk dealer will desire answered. The most important of these concern its palatability and appearance as compared with pasteurized milk.

PALATABILITY OF HOMOGENIZED MILK

Doan (*1*) states that several years ago 33 members of the winter dairy short course at Pennsylvania State College were asked to give their preference between two samples of milk. One sample was normal raw milk, and the other was prepared by homogenizing the same milk at 100° F. (38° C.). Of the 33 persons, 28 chose the homogenized milk, from which he concluded it would seem that homogenized milk is more palatable to most people than normal milk. A similar conclusion is reported by Irwin (*12*), who found that the consumption of milk increased notably in several of the State institutions in Pennsylvania when homogenized milk was substituted for normal milk. For example, at the Mount Alto Sanatorium for young people the per capita consumption rose from 1½ quarts to 2 quarts. Hudon (*11*) also states that the homogenization of milk has undoubtedly increased the per capita consumption of milk and milk products in the localities where it has been featured.

The results of experiments in the Bureau of Dairy Industry were not so decisively in favor of homogenization. In one experiment, pasteurized milk containing an average of 4.1 percent butterfat was homogenized under closely controlled conditions at 2,500 pounds pressure, at the pasteurizing temperature, 142° F. (61° C.), and compared with the same pasteurized milk which had not been homogenized. A total of 470 opinions were obtained on 470 samples of each of the milks. The following results were obtained: 178 opinions, or 37.9 percent, were in favor of the unhomogenized milk; 172 opinions, or 36.6 percent, were in favor of the homogenized milk; and 120 opinions, or 25.5 percent, showed no choice between the two samples. In other words, with milk of good flavor, properly homogenized, 62.1 percent of the opinions showed no prejudice against homogenized milk, and the preferences for homogenized milk and unhomogenized milk were practically equal.

HOMOGENIZATION AS A SOURCE OF ABNORMAL FLAVORS

IN RAW MILK

Dorner and Widmer (*4*) reported that homogenization caused raw milk and raw cream to become distinctly rancid after a few hours. The development of rancidity increased as the size of the fat globules diminished. This rancidity was caused by a lipase. Halloran and Trout (*6*) state that the titratable acidity of raw milk was always raised by viscolization. Along with the increase in acidity a rancid flavor always developed. Pasteurization of the milk before viscolization prevented both the rise in acidity and the development of rancid flavor. These changes appeared to be caused by a lipase. Therefore they concluded that raw milk cannot be viscolized for commercial purposes. Doan (*2*) used the increase in titratable acidity, together with pH and surface-tension data, in determining

critical preheating temperature for inhibiting rancidity in homogenized milk.

Experimental work in this Bureau indicates that there is an optimum homogenizing temperature for the development of a rancid flavor in raw homogenized milk. This temperature ranges from 30° to 40° C. (86° to 104° F.). Raw milk homogenized within this temperature range, although cooled and stored at a low temperature, became rancid within 18 hours after homogenization. Milk homogenized at temperatures ranging from 4.5° to 10° C. (40° to 50° F.), although remaining of good flavor for this length of time, developed an abnormal flavor upon further aging. Milk homogenized at 15° and 55° C. (59° and 131° F.) developed a slight rancid flavor; that homogenized at 20°, 25°, and 45° C. (68°, 77°, and 113° F.) had developed the rancid flavor at the end of 18 hours, but to a lesser degree than the milk homogenized within the optimum temperature range. The milk homogenized at 60° C. (140° F.) remained of normal flavor.

Further evidence that there is an optimum temperature for the development of a rancid flavor is shown by the time required for the flavor to develop in the milk after homogenization at different temperatures. In table 1, the plus (+) marks indicate the relative development of rancidity in milk homogenized at 3,000 pounds pressure, at different intervals of time after being homogenized.

TABLE 1.—*Development of rancidity*[1] *in milk homogenized at 3,000 pounds pressure, at different intervals of time after homogenization*

Homogenizing temperature		Relative rancidity of homogenized milk—					
		At 2 hours		At 3 hours		At 4 hours	
		Cooled	Uncooled	Cooled	Uncooled	Cooled	Uncooled
°C.	° F.						
20	68	−	+	+	++	++	++++
30	86	+	++	++	++++	+++	+++++
40	104	+	++	++	++++	+++	+++++
50	122	−	−	−	−	−	+

[1] Minus marks indicate no rancidity and plus marks indicate the relative development of rancidity.

The rancid flavor not only appeared sooner but was more intense when the milk was homogenized at 30° or 40° C. than at 20° or 50°.

As shown in table 1, cooling and storing the homogenized milk at a low temperature apparently retarded the development of the rancid flavor. However, the cooled samples showed the same degree of rancidity as the uncooled samples within 10 minutes after warming.

Varying the homogenizing pressure did not affect the development of the rancid flavor. However, if complete homogenization was not obtained, thereby permitting a partial separation of the cream, a greater length of time was required for the rancid flavor to develop and the flavor was less intense.

This work shows that homogenization cannot be applied to raw milk for commercial purposes. It also indicates that in handling raw milk care must be used not to subject it to any process or agita-

tion which might have an homogenizing effect, especially at temperatures within the optimum temperature range for causing a rancid flavor.

IN PASTEURIZED MILK

Pasteurized milk was homogenized through the same temperature range as was used in the experiments with raw milk. Upon aging, the pasteurized milk that had been homogenized at a temperature within the optimum range (30° to 40° C.) for the development of rancid flavor, developed what is best described as a slight oxidized flavor. The milk homogenized at temperatures outside the optimum range did not always develop a flavor which could be identified. At the lower temperatures, however, it frequently developed a slightly bitter flavor. The pasteurized milk homogenized at 60° C. (140° F.) remained of good flavor upon aging.

When milk was pasteurized immediately after being homogenized, no abnormal flavors due to homogenization developed upon aging, regardless of the homogenizing temperature. Likewise, when milk was pasteurized and then immediately homogenized at the pasteurizing temperature, no abnormal flavors developed upon aging.

In the preparation of homogenized milk for market purposes the milk may be either pasteurized and then immediately homogenized at or above the temperature at which it was pasteurized, or else pasteurized immediately after homogenization. From a sanitary standpoint, the better practice would be to place the homogenizer between the preheater and the pasteurizer, because the milk would come into contact with one less piece of apparatus after pasteurization. If this method is followed, care must be taken to prevent delay in the pasteurizing process. It is advisable to homogenize the milk at or above the pasteurizing temperature, regardless of whether the process of homogenization is performed before or after pasteurization, because the higher temperature of homogenization insures against abnormal flavors, and because at the lower temperatures difficulty is encountered in obtaining complete homogenization.

SEDIMENT IN HOMOGENIZED MILK

One of the objections to homogenized milk is that when the milk stands after bottling, a ring of sediment frequently forms on the bottom of the bottle. Trout and Halloran (*14*) state that this sediment appears to be very fine dirt, probably in a mixture with some milk solids; Doan and Minster (*3*) concur with Trout and Halloran by stating that the sediment is undoubtedly fine dirt, which is aggregated and caused to settle out by the action of the homogenizer. While the sediment has the general appearance of separator or clarifier slime, Trout and Halloran (*15*) state that—

> Although the deposit from homogenized milk compared with clarifier slime in respect to the percentage of water and total solids, the percentage of fat was from two to three times higher than that in clarifier slime, while the solids-not-fat were considerably lower.

The writer was unable to identify the real character of the sediment in homogenized milk by microscopic examination. However, when slides of this sediment were prepared and stained by the Breed method, it was found to consist largely of leucocytes and epithelial cells (fig. 1).

MILK CONTAINING APPROXIMATELY 1,000,000 CELLS PER CUBIC CENTIMETER

To determine whether homogenization of milk permits the cells therein to settle out, cell counts of milk from different points in the bottle were made with both homogenized and unhomogenized milk at intervals over a period of 4 days. The samples were obtained by drawing 10 cc of milk from the top, middle, and bottom of each bottle with a 10-cc pipette. Table 2 shows the average cell counts at different depths in bottled homogenized and unhomogenized milk.

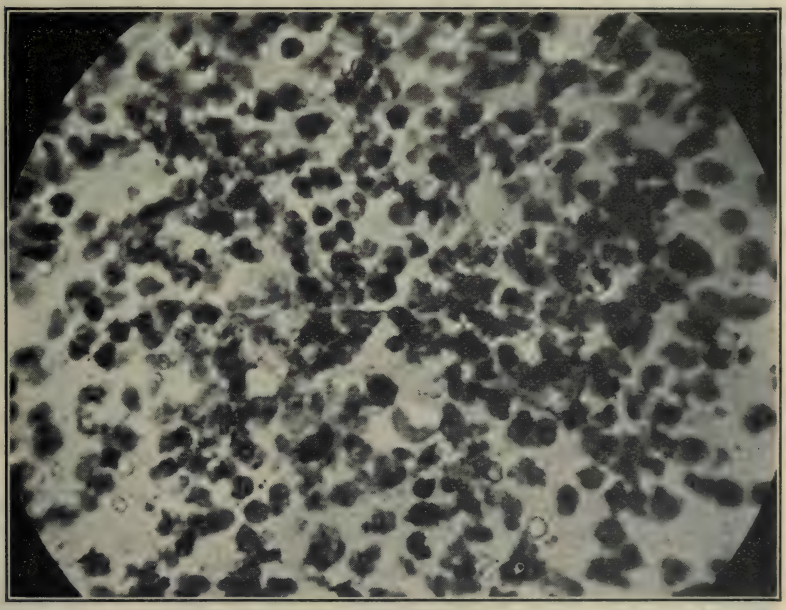

FIGURE 1.—Microscopic field showing leucocytes in the sediment from homogenized milk. (Microscopic factor 550,000.)

TABLE 2.—*Average cell counts of pasteurized unhomogenized and homogenized milk at different points in the bottle*

Character of milk and storage interval	Average cell count per cubic centimeter—		
	At top of bottle	At middle of bottle	At bottom of bottle
Pasteurized unhomogenized milk:			
At 3 hours	6, 563, 300	128, 300	128, 300
At 24 hours	8, 818, 300	119, 200	91, 700
At 48 hours	8, 963, 300	55, 000	55, 200
At 72 hours	9, 725, 800	64, 200	42, 500
At 96 hours	9, 863, 300	64, 200	49, 500
Pasteurized milk homogenized at 3,000 pounds pressure:			
At 3 hours	650, 800	971, 700	1, 127, 500
At 24 hours	467, 500	800, 800	2, 640, 000
At 48 hours	256, 700	534, 200	3, 657, 500
At 72 hours	155, 800	485, 800	5, 105, 800
At 96 hours	150, 000	340, 000	6, 178, 300

Table 2 shows that in unhomogenized milk the cells, to a large extent, are carried up with the fat globules and remain in the cream layer (figs. 2 and 3). In homogenized milk there is no rising of fat globules, so that the cells, which apparently have a higher specific gravity than milk, are released from the influence of rising fat globules and settle to the bottom of the bottle (figs. 3 and 4). The cells collecting on the bottom of the bottle appear as sediment in the milk.

There was no correlation between the homogenizing pressure and the formation of sediment. There was usually pronounced sediment at the end of 24 hours and the quantity was apparently the same, regardless of the homogenizing pressure. However, if the pressure was not sufficient to obtain complete homogenization, the sediment

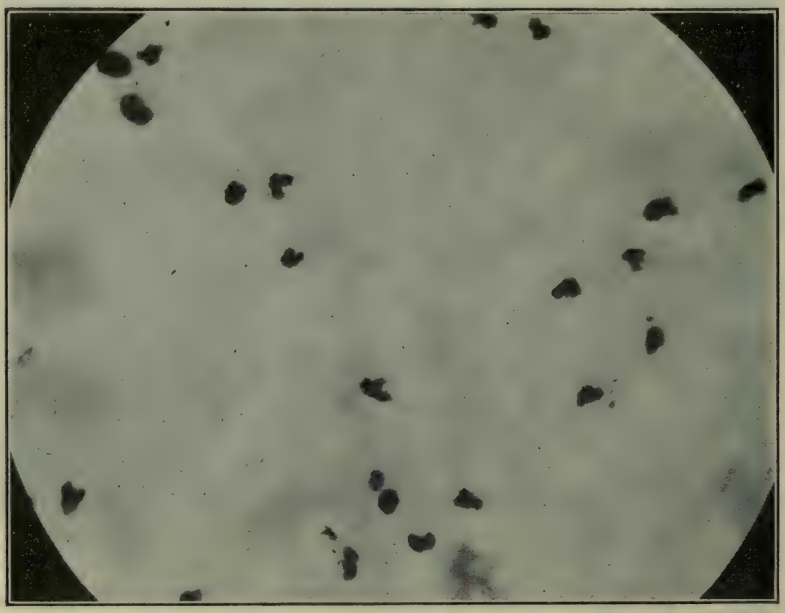

FIGURE 2.—Microscopic field showing leucocytes in the top or cream layer of unhomogenized milk. (Microscopic factor 550,000.)

in the bottled milk was less pronounced. This was due to the formation of a thin cream layer which contained a comparatively large number of cells.

MILK CONTAINING LESS THAN 100,000 CELLS PER CUBIC CENTIMETER

In order to substantiate the fact that the sediment in homogenized milk consists largely of leucocytes and epithelial cells, an experiment was conducted with milk having a low cell count, in the same manner as the preceding experiment. This milk was obtained by selecting cows giving milk with cell counts below 100,000 per cubic centimeter. The average cell count of the mixed milk used in this experiment was slightly below 90,000 per cubic centimeter. The milk was produced and handled in the same manner as the milk

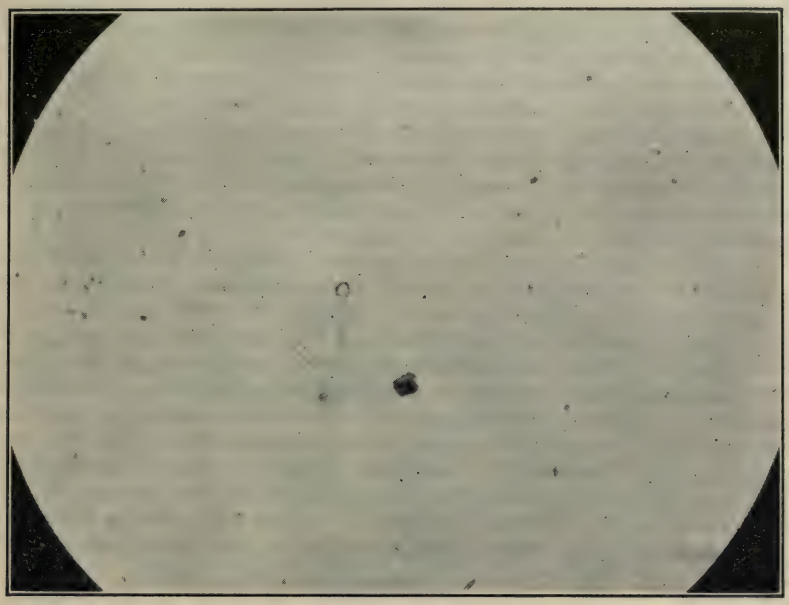

FIGURE 3.—Typical microscopic field from the middle of the bottles of both homogenized and unhomogenized milk; also the bottom of unhomogenized and the top of homogenized milk. Many fields contain no leucocytes. (Microscopic factor 550,000.)

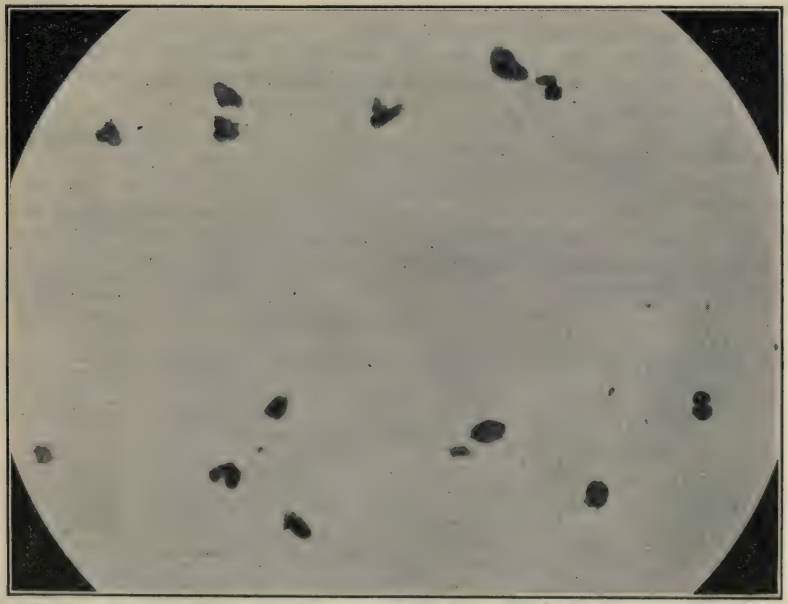

FIGURE 4.—Microscopic field showing leucocytes in the bottom of homogenized milk. (Microscopic factor 550,000.)

used in the previous experiment. When this milk was homogenized, bottled, and stored at a low temperature, no trace of sediment could be detected even after 120 hours. The cell counts from different points in the bottle showed that the same movement of cells took place as in the previous experiment. After a storage period of 96 hours, the unhomogenized milk had an average cell count of 348,300 per cubic centimeter in the cream layer and the homogenized milk had an average cell count of 337,500 per cubic centimeter in the milk at the bottom of the bottle. This number of cells, however, was not sufficient to cause sediment or discoloration.

To obtain milk with a low cell count it is advisable to select cows which are not nearing the end of their lactation period. In this work it was found that the milk produced by cows near the end of the lactation period not only contained considerable udder tissue but the cells were, to a considerable extent, in groups or clumps. Both of these factors tend to increase sedimentation in homogenized milk. In fact, the pasteurized samples of such milk which had not been homogenized frequently contained the sediment to nearly the same degree as the homogenized samples. Evidently the rising fat globules are incapable of carrying up and holding the clumps of cells and udder tissue, so that these settle to the bottom of the bottle and appear as sediment, even in milk which has not been homogenized.

CLARIFIED MILK

Inasmuch as the sediment in homogenized milk is formed mostly of cells, clarification of the milk should help to prevent its formation. Milk with a comparatively high cell count (above 1,500,000 per cubic centimeter) was clarified, otherwise the experiment was conducted in the same manner as described previously. The average cell count of the clarified milk was slightly below 200,000 per cubic centimeter. Table 3 shows the average cell counts, at different points in the bottle, for both unhomogenized and homogenized clarified milk, a few hours after bottling and at daily intervals.

TABLE 3.—*Average cell counts of pasteurized clarified unhomogenized and homogenized milk, at different points in the bottle*

Character of milk and storage interval	Average cell count per cubic centimeter—		
	At top of bottle	At middle of bottle	At bottom of bottle
Pasteurized clarified unhomogenized milk:			
At 3 hours	1,410,800	76,600	137,500
At 24 hours	1,837,000	49,500	88,000
At 48 hours	2,068,000	38,500	44,000
At 72 hours	2,222,000	44,000	33,000
At 76 hours	2,568,100	38,500	38,500
Pasteurized clarified homogenized milk, homogenized at 3,000 pounds pressure:			
At 3 hours	211,750	201,700	366,700
At 24 hours	77,000	121,000	610,500
At 48 hours	60,500	88,000	628,500
At 72 hours	38,500	99,000	737,000
At 96 hours	44,000	88,000	924,000

Comparison of the results in table 3 with those in table 2 shows that in general the same movement of cells takes place in clarified milk as was found in the unclarified milk. Nevertheless, from a

practical standpoint, clarification prevents the formation of sediment in homogenized milk. However, a careful examination frequently disclosed a slight discoloration in the bottom of the bottle of clarified homogenized milk after it had stood for over 48 hours. When the aged milk was poured from the bottle without mixing, that clinging to the bottom of the bottle was also frequently of a grayish tint. This adhesion of cells on the bottom of the bottle probably accounts for the fact that the bottom portion of the homogenized milk had a lower cell count than the cream layer of the unhomogenized milk.

EFFECT OF HOMOGENIZATION ON THE BABCOCK TEST

In the experiments described herein the Babcock test was used in making butterfat determinations on the milk before and after homogenization. Halloran and Trout (*6*) state that viscolization appears to have no effect on either the Babcock test or the specific gravity of milk. The writer found that in every case the homogenized milk showed a slightly lower fat test than the same milk before being homogenized. The difference ranged from 0.05 to 0.15 percent, with an average of 0.1 percent. This is in agreement with Hollingsworth (*19*), who states:

> Dealers have come to realize that a 3.6 percent butterfat pasteurized milk will not yield a 3.6 percent butterfat homogenized milk; that is, by actual Babcock fat test. The reason for the discrepancy is based on the fact that the fat globules are so finely divided that some of them, the more minute ones, cannot be raised with the fat column in the Babcock fat test bottle by the combined action of sulphuric acid and centrifugal force. Again, one must remember that under usual conditions, with ordinary milk, as much as one-tenth of 1 percent fat remains unseparated in the neck of the Babcock bottle. With homogenized milk this amount may be increased to as much as two- or three-tenths of 1 percent.

SPECIFIC GRAVITY OF HOMOGENIZED MILK

Williams and Leighton (*19*) have shown that the volume of an ice-cream mix may be increased by the incorporation of air during homogenization. The writer found that rarely was there sufficient air incorporated in milk by homogenization to affect its lactometer reading. However, by using a Westphal balance it was found that homogenization did incorporate sufficient air in milk to affect its specific gravity slightly. Table 4 shows the average decrease in specific gravity due to homogenization.

TABLE 4.—*Average decrease in specific gravity of milk due to homogenization*

Hours after homogenization (number)	Average decrease in specific gravity of—	
	Milk homogenized at 1,000 pounds	Milk homogenized at 3,000 pounds
1	0.00076	0.00085
24	.00042	.00045
48	.00031	.00041
72	.00023	.00038

Homogenization at 3,000 pounds pressure incorporated slightly more air in milk than homogenization at 1,000 pounds pressure. Apparently the air is not permanently incorporated, as the difference in the specific gravity of the homogenized and the unhomogenized milk became less upon aging, although it was stored in capped bottles.

The average difference in specific gravity of the milk before and after homogenization at 3,000 pounds, as shown by table 4, ranged from 0.00085 at 1 hour to 0.00038 at 72 hours. The greatest difference in specific gravity found in any one sample after homogenization at 3,000 pounds pressure was 0.0011 at 1 hour and 24 hours, 0.0007 at 48 hours, and 0.0006 at 72 hours. The average and extreme ranges, taken together, indicate that homogenization does not affect the specific gravity of milk to the extent of changing materially the percentage of total solids as calculated from the specific gravity.

SUMMARY AND CONCLUSIONS

Pasteurized homogenized milk is as palatable to the average consumer as is pasteurized milk.

Homogenization causes the development of rancidity in raw milk to such an extent that the process cannot be applied to raw milk for commercial purposes.

The optimum temperature of homogenization for the development of rancidity in raw milk ranges from 30° to 40° C. (86° to 104° F.).

In handling raw milk care should be taken not to subject it to any process or agitation which might have an homogenizing effect, especially at temperatures within the optimum temperature range for the development of rancidity.

In the preparation of homogenized milk for market purposes the milk should be homogenized immediately after being pasteurized, or pasteurized immediately after being homogenized.

Homogenization should be done at or above the pasteurizing temperature.

The sediment frequently found in homogenized milk consists largely of leucocytes and epithelial cells. In unhomogenized milk the cells are carried up with the rising fat globules and held in the cream layer. In homogenized milk these cells settle to the bottom.

To prevent sedimentation in homogenized milk the milk should be clarified before it is homogenized.

The Babcock test for butterfat does not give as high a fat reading for homogenized milk as it does for the same milk before homogenization.

Although the specific gravity of milk is lowered slightly by homogenization, this does not occur to such an extent that it affects materially the percentage of total solids as calculated from the specific gravity.

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DEVELOPMENT OF THE SWINE NEMATODE STRONGYLOIDES RANSOMI AND THE BEHAVIOR OF ITS INFECTIVE LARVAE

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INTRODUCTION

In view of the fact that several observers, notably Perroncito (*19*),[1] Reisinger (*22*), and Marotel (*16*), have shown, on the basis of clinical studies, that *Strongyloides* is pathogenic for pigs, the writer undertook a study of the life cycle and behavior of the infective larvae of *S. ransomi*, the species of common occurrence in pigs in the United States, for the purpose of discovering facts that might be of value in connection with the control of this parasite. Schwartz and Alicata (*25*) have already briefly described some of the essential features in the preparasitic life history of *S. ransomi*. However, these writers were primarily concerned in establishing the validity of *S. ransomi* as a new species, and their observations

[1] Italic numbers in parentheses refer to Literature Cited, p. 29.

on the life cycle were only incidental to the main thesis of their paper. In the course of the writer's study, numerous additional details concerning the preparasitic development of *S. ransomi* and many facts relating to the development of the parasite in its host have been brought to light which, together with the data already supplied by Schwartz and Alicata, make possible the presentation of a virtually complete account of the life history of this species.

SCOPE AND METHODS OF INVESTIGATION

The investigation reported in this bulletin was conducted at Beltsville, Md., from October 1932 to May 1933. The program of the work was as follows: (1) The intermediate stages in the heterogeneous preparasitic development of *Strongyloides ransomi* were studied in feces and charcoal cultures and in water cultures to which helminthologically sterile fecal extract was added at the time the larvae issued from the eggs; (2) the effects of various environmental conditions on the survival of infective larvae were determined; (3) the reactions of the infective larvae to stimuli and environment were observed; (4) the modes of infection were established experimentally; and (5) the development of the parasite and the clinical symptoms produced in pigs, the normal hosts, and in other hosts were studied.

Larvae for all experimental purposes were obtained from cultures prepared from feces passed by pigs which harbored no parasites other than *S. ransomi*. All cultures were incubated at room temperature (20° to 24° C.). With two exceptions, the pigs used for oral and skin-infection experiments were raised parasite free. All experimental animals were kept in individual cages under conditions of strict sanitation designed to prevent extraneous infection or reinfection with *S. ransomi* or other worm parasites. A thermostatically controlled electric refrigerator was used for experiments involving low temperatures. The Baermann isolation apparatus was routinely used for the purpose of obtaining larvae from cultures, and the failure to obtain larvae from a culture by means of this apparatus was accepted as indicative of the absence of living larvae in the culture. The Baermann apparatus was also used for the isolation of parasitic larvae from organs and tissues.

PREPARASITIC DEVELOPMENT OF STRONGYLOIDES RANSOMI

MODES OF DEVELOPMENT

Schwartz and Alicata have shown that both the direct and indirect modes of development occur in the life cycle of *Strongyloides ransomi*, as they do in the life cycle of other species of the genus *Strongyloides*. Sandground (*24*), who studied the quantitative relationship between direct and indirect development in species of *Strongyloides* from different hosts, showed this relationship to be subject to constant changes. The writer has observed that cultures consisting of a mixture of animal charcoal and feces from young pigs harboring *S. ransomi* often showed predominantly direct development early in the history of an infestation and later, as the infestation waned, usually showed mainly indirect development. Both modes of development usually occur in a single fecal culture. However, records of

two cultures, prepared from the feces of two infested pigs, indicate that only unisexual adults of *S. ransomi* were present about 48 hours after the cultures had been prepared. Schwartz and Alicata found that the number of males present in 48-hour cultures was small compared with the number of females. The writer has found this to be the usual occurrence in cultures. In a few cultures no males were seen, whereas in one 50-hour culture 79 males and only 40 females were found. Hence it appears that cultures prepared from feces containing eggs of *S. ransomi* may exhibit practically every possible relationship between the two modes of development and that the proportion of males to females, when indirect development occurs, is variable.

DEVELOPMENT OF INFECTIVE LARVAE FROM EGGS OF THE PARASITIC FEMALE

EGGS

Schwartz and Alicata have described the size and morphology of eggs of *Strongyloides ransomi* which are passed in the feces of infested pigs. They state that the eggs are from 45μ to 55μ long and from 26μ to 35μ wide. Occasionally, eggs slightly longer or wider than indicated above have been found by the writer. The eggs are embryonated when oviposited.

The time required for larvae to hatch from the eggs eliminated with the feces of infested pigs is variable. Young larvae were found in the water used to flush the small intestine of infested animals at post-mortem examination about 4 hours after the water and intestinal contents were mixed. The vast majority of eggs in fecal or water cultures hatch in from 12 to 18 hours at room temperature (20° to 24° C.).

FIRST-STAGE LARVAE

Newly hatched " rhabditiform " larvae are from 220μ to 240μ long. Just after hatching most larvae show a separation of the cuticle at the anterior end, which is early evidence of the approach of the first molt (fig. 1, *A* and *B*). A newly hatched larva, cultured in water, showed the following size relationships: Length, 230μ; width in region of esophageal bulb, 18μ; length of pharynx, 5.5μ; distance from nerve ring to anterior end, 55μ; length of esophagus, 69μ; length of genital primordium, 10.5μ; length of tail, 39μ. In first-stage larvae, a short region of the esophagus immediately posterior to the pharynx or mouth cavity differs in structure from the remainder of the corpus. The genital primordium, which appears to contain two small circular germinal cells, is slightly anterior of the midpoint between the anus and the junction of the esophagus and intestine. It remains small throughout the first stage, retains its characteristic oval shape, and at the time of the first molt is from 10μ to 15μ long.

As the first-stage larvae grow, their morphology is not perceptibly modified. Increasing evidence of the separation of the cuticle from the body of the larva is noted in the course of the first 12 hours of its existence. The cuticle first loosens from the body in the head and tail regions (fig. 1, *C*). Usually complete separation of the cuticle occurs when the larvae are from 275μ to 325μ long (fig. 1, *D*).

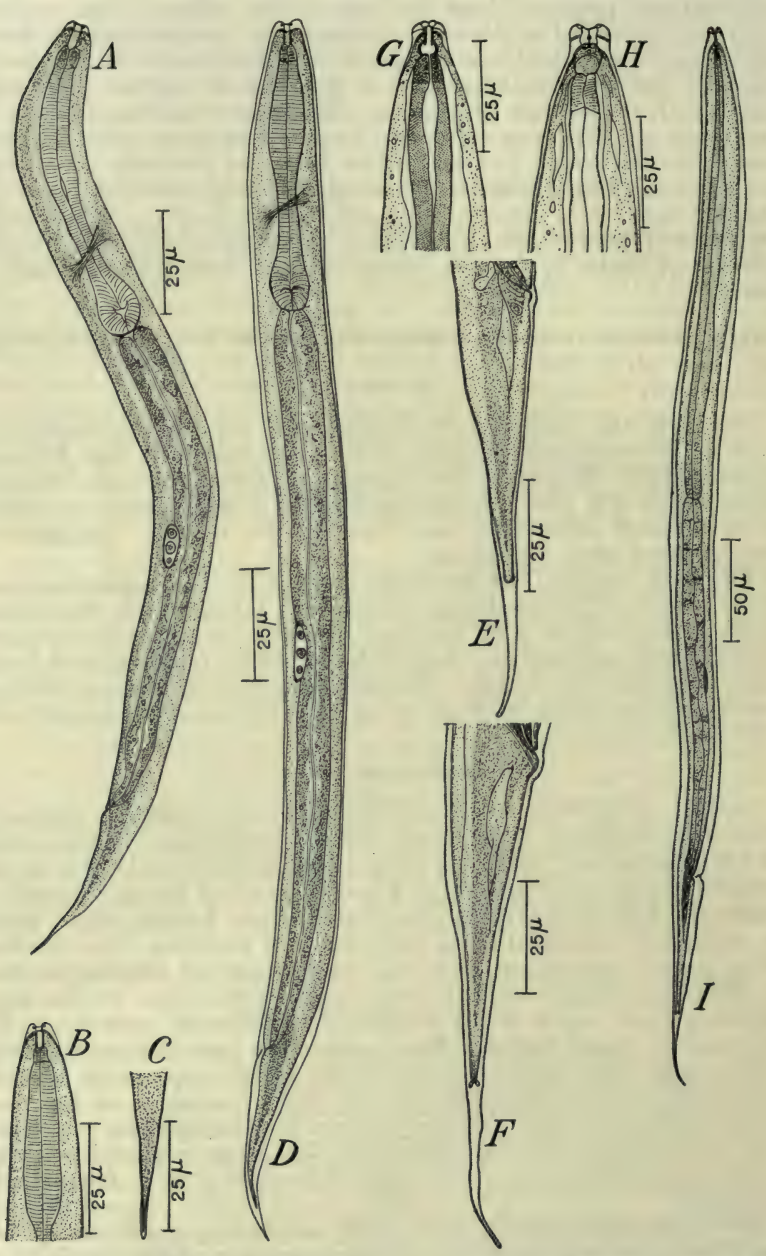

FIGURE 1.—Various stages in the development of strongyliform larvae of *Strongyloides ransomi* (direct cycle): *A*, First-stage larva (newly hatched); *B*, anterior end of first-stage larva; *C*, posterior end of first-stage larva; *D*, larva in first ecdysis; *E*, posterior end of second-stage larva, showing early phase of second ecdysis; *F*, posterior end of second-stage larva, showing buds at tip of tail; *G* and *H*, anterior ends of second-stage larvae; *I*, larva in late phase of second ecdysis.

The first molt occurs from 12 to 18 hours after the larvae hatch. The casting of the sheath was observed in a larvae only 290μ long, but as a rule, larvae about 325μ long have not yet molted. At the time the cuticle is cast, the larvae again show evidence in the head region of the approach of another molt.

SECOND-STAGE LARVAE

Immediately following the first molt, second-stage larvae are not distinguishable from first-stage larvae by any definite structural differences except for the absence of appreciable separation of the cuticle in the former. However, in 36-hour cultures, larvae were found undergoing transition to the so-called "filariform", more properly, strongyliform, state. The writer's observations on the morphological changes during the second ecdysis, by virtue of which the larvae assume the strongyliform characteristics, are essentially similar to those of Leuckart (*12*) on larvae of *Strongyloides stercoralis*.

When the larvae have reached a length of from 375μ to 400μ, the tail has increased considerably in length and fineness, and the second cuticle has already become separated to some extent from the body in the head and tail regions. A larva 420μ long exhibited the first transitional step in the process of the formation of the tail characteristic of third-stage or strongyliform larvae. A shorter, blunt, slightly oblique tail is formed through the separation and disintegration of the fine filamentous tip (fig. 1, *E*). Subsequently two very small lateral oval processes or buds appear at the tip of this newly formed tail (fig. 1, *F*); later these fuse completely with the basic tail process to form the characteristic notched tail. Sandground's observation (*23*) based on a study of the development of several species of *Strongyloides*, to the effect that "* * * the notch in the tail is formed by the rupture of the tail at the time that the filariform larvae emerged from the old cuticula * * *" has not been confirmed by the writer.

Ordinarily the esophagus begins to lengthen and lose its "rhabditiform" character before the changes in the morphology of the tip of the tail are completed. Some larvae in which the tail is already notched still retain the esophageal valve and show no conspicuous increase in the length of the esophagus. However, before the second molt is completed, the esophagus attains a completely strongyliform structure. Complicated changes appear in the structure of the buccal cavity and head. These changes result in the loss of the mouth-cavity characteristic of first-stage and early second-stage larvae. The head structure of larvae which were undergoing the transition to the strongyliform stage is illustrated in figure 1, *G* and *H*. During the second stage the genital primordium is not noticeably modified in structure except for a more pronounced slenderness; it is from 10μ to 17μ long when the transitional changes described above are completed.

The size attained by the larvae during the second stage is variable and depends to some degree on environmental conditions during the period of feeding and growth. Ordinarily larvae from 450μ to 550μ long have completed their development to the strongyliform stage,

and the second molt (fig. 1, *I*) occurs in the manner usual among larval nematodes. In charcoal and feces cultures, the kind used throughout this investigation for the most part, the second molt may occur at room temperature in less than 48 hours after the preparation of the cultures.

THIRD-STAGE OR INFECTIVE STRONGYLIFORM LARVAE

Schwartz and Alicata have given a description and figure of the strongyliform larva of *Strongyloides ransomi*, and it is unnecessary, therefore, to redescribe this stage. In the writer's experience, larvae obtained from eggs cultured in water, a procedure which was occasionally followed, tend to be smaller than those which develop in feces and charcoal cultures. From both sources, strongyliform larvae less than 500μ long have been frequently obtained. The genital primordium of third-stage larvae varies from 10μ to 17μ in length, usually from 12μ to 14μ.

DEVELOPMENT OF FREE-LIVING UNISEXUAL ADULTS FROM EGGS OF THE PARASITIC FEMALE

FIRST-STAGE LARVAE

The time required for the larvae to hatch from the eggs at room temperature has been given previously. Newly hatched larvae of this cycle are from 230μ to 250μ long and are distinguishable from first-stage larvae of the direct cycle, already described, only by the fact that the former possess a larger genital primordium, within which, particularly as growth proceeds, several rounded cells are visible (fig. 2, *A*). In four young first-stage larvae 230μ, 245μ, 250μ, and 265μ long, the genital primordium was 17μ, 15.5μ, 20μ, and 23μ long, respectively. A newly hatched larva showed the following typical size relationships: Length, 255μ; width in region of esophageal bulb, 16μ; distance from nerve ring to anterior end, 50μ; length of esophagus, 75μ; length of genital primordium, 19.5μ; length of tail, 50μ.

The larvae show evidence of the impending first molt immediately after hatching, when it is already possible to discern the separation of the cuticle from the body of the larva in the head region. The separation of the cuticle progresses as the larvae grow, and is next observed in the tail region. When the larvae have attained a length of from 300μ to 350μ, the separation of the cuticle is usually complete and the genital primordium, which has become irregularly elongate oval in outline, has reached a length of from 21μ to 26μ (fig. 2, *B*).

First-stage larvae were observed in the act of casting the first cuticle when they were from 300μ to 350μ long. It was noted, however, that some larvae slightly more than 350μ long had not yet cast their sheaths, although the cuticle was completely separated from the body. The first molt occurs about 10 hours after the larvae hatch.

SECOND-STAGE LARVAE

Since the molting and development of an individual larva were not followed in sequence from the first stage to the free-living adult

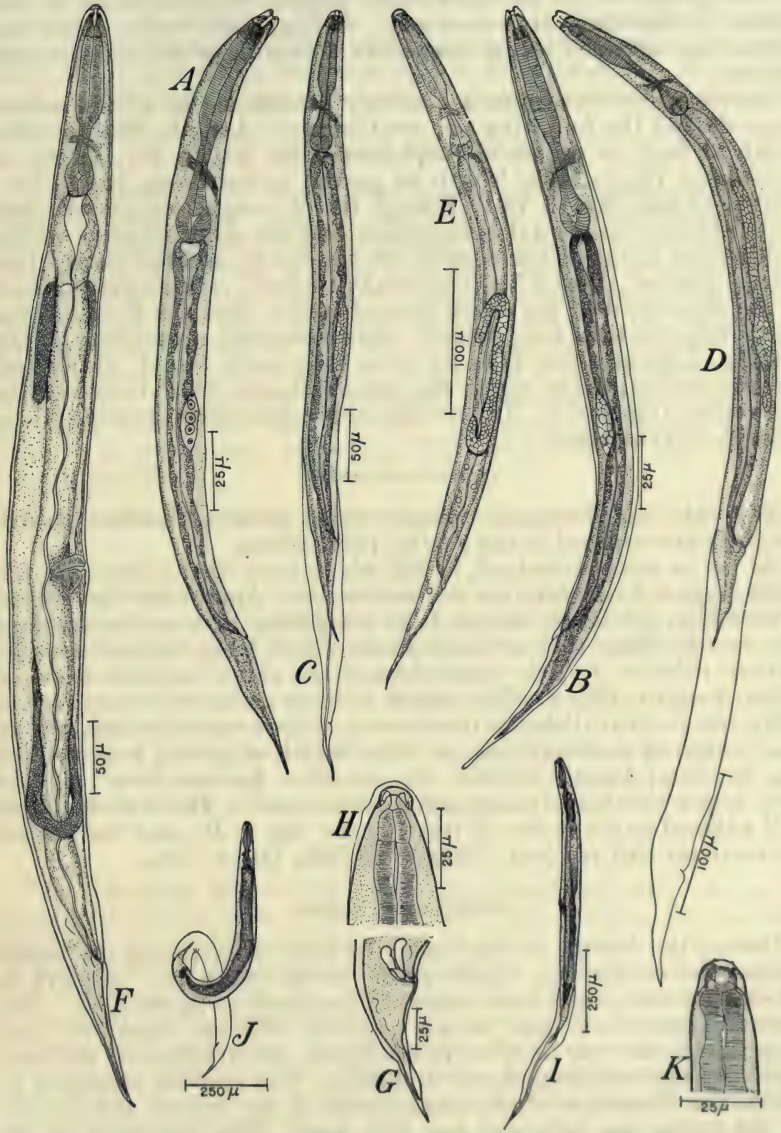

FIGURE 2.—Various stages in the development to free-living unisexual adults of *Strongyloides ransomi*: *A*, First-stage larva (newly hatched); *B*, larva in first ecdysis; *C*, second molt; *D*, third molt; *E*, larva in early fourth stage; *F*, larva (female) in fourth ecdysis; *G*, posterior end of male larva in fourth ecdysis; *H*, anterior end of male larva in fourth ecdysis; *I*, female larva undergoing fourth molt; *J*, male larva undergoing fourth molt; *K*, anterior end of adult female.

state, separation into " rhabditiform " second and third stages is based on the fact that larvae isolated from cultures about 24 to 36 hours old and which were observed in the act of casting their sheaths, are of two groups so far as size and the degree of development of the genital primordium are concerned. A final molt occurs when the larvae have attained sexual characters, following which they become adults.

Larvae which have been tentatively determined as of the second stage showed the following size relationships: Length, 300μ to 450μ; width of body in region of esophageal bulb, 20μ to 25μ; length of esophagus, 75μ to 106μ; length of genital primordium, 25μ to 70μ; length of tail, 60μ to 78μ. Except for the continued growth and elongation of the genital primordium and the multiplication of the cells within it, the morphology is not noticeably modified during this stage. Larvae about 375μ long usually afford very slight evidence of the separation of the newly formed cuticle from the body; larvae from 400μ to 450μ long usually show complete separation of the cuticle. Larvae from 415μ to 435μ long were found which had already molted and to which the cast-off sheath still adhered in the tail region (fig. 2, *C*). The second molt occurs from 22 to 24 hours after the larvae hatch.

THIRD-STAGE LARVAE

The only morphological changes which occur as further growth proceeds are confined to the genital primordium.

So far as was determined, larvae which have been referred to the third stage did not show sex differentiation. Apparently the genital primordium of larvae which later transform into males develops less rapidly than that of individuals which later become females. Larvae referred to this stage showed the following size relationships: Length, 420μ to 550μ; width of body in region of esophageal bulb, 25μ to 31μ; distance from nerve ring to anterior end, 70μ to 90μ; length of esophagus, 92μ to 110μ; length of genital primordium, 60μ to 160μ; length of tail, 70μ to 80μ. Larvae from 480μ to 550μ long which had already molted were found. The cast-off cuticle still adhered to the bodies of these larvae (fig. 2, *D*), and the genital primordium had reached a length of from 60μ to 150μ.

FOURTH-STAGE LARVAE

During the fourth, or final, stage of their development the larvae assume the morphology of the adults of the two sexes. A larva in an early phase of the final stage is illustrated in figure 2, *E*. The genital primordium has become slightly reflected anteriorly and posteriorly. As will be noted in the figure, the structure of the head simulates the condition found in adults. The smallest specimen in which the formation of the musculature of the vagina and the slit of the vulva was indicated was 500μ long. The formation of the vulva and growth of the ovaries and uterus, as well as the formation of the testis and spicular apparatus of the male, may be followed in detail during this stage. The cuticle, which can first be observed as separate from the body of the larva at the head end, can also be distinctly seen in the vulvar region of female larvae from 600μ to 700μ long. Female larvae 750μ long usually show more or less com-

plete separation of the cuticle (fig. 2, *F*). The anterior and posterior extremities of a male larva enveloped in its sheath, just preceding the final molt, are illustrated in figure 2, *G* and *H*.

Female larvae from 750μ to 875μ long were observed in the act of casting the fourth-stage cuticle (fig. 2, *I*). At this stage the uterus does not contain eggs. The ovaries appear to be completely formed. Male larvae about 750μ long were seen casting the sheath of the final molt. The spicular apparatus is completely formed at this time (fig. 2, *J*).

ADULT MALES AND FEMALES

Adults were found in cultures maintained at room temperature after incubation for from 36 to 48 hours. A description of the adults is unnecessary, since Schwartz and Alicata have described and figured both sexes. Figure 2, *K* illustrates the structure of the anterior end of a female in more detail than is shown in the figures of these authors. Schwartz and Alicata state that the spicules of " rhabditiform " males of *S. ransomi* are from 26μ to 29μ long. These authors measured the length of the spicules in a straight line from tip to tip. The spicules of six male specimens, which the writer measured along the arc of their curvature by means of the method of projection, were 36μ, 37.5μ, 39.5μ, 37.5μ, 36μ, and 35μ long, respectively.

DEVELOPMENT OF INFECTIVE LARVAE FROM EGGS OF THE FREE-LIVING FEMALE

EGGS

Fully formed eggs, measured while still in the uterus of free-living females, were from 39μ to 50μ long and from 27μ to 32μ wide. Ordinarily, the eggs did not contain a vermiform embryo when they passed out of the vagina of the female.

Larvae hatched from the eggs in water in about 12 hours. In some cases eggs which were within the uteri of dead female worms had hatched, and the liberated larvae were seen feeding within the body of the disintegrating mother worm. This phenomenon was not observed in living females during the active egg-producing period.

FIRST-STAGE LARVAE

The first-stage larvae (fig. 3, *A*) are morphologically similar to those of the direct cycle of development. The separation of the cuticle (fig. 3, *B* and *C*) also progresses as was described in the case of first-stage larvae of this cycle of development. No noticeable morphological changes precede the first molt. The genital primordium remains small and is from 10μ to 12.5μ long when the first molt occurs. As long as 48 hours may be required for the larvae to molt in water, particularly when food is not abundant. Larvae from 310μ to 340μ long which had already molted were noted. The cast-off cuticle still adhered to these larvae (fig. 3, *D*).

SECOND-STAGE LARVAE

The transition to strongyliform larvae, which occurs during the second stage, takes place in the same manner as has been described in the case of larvae of direct, or homogonic, development. The larvae are from 400μ to 450μ long when they begin to undergo this

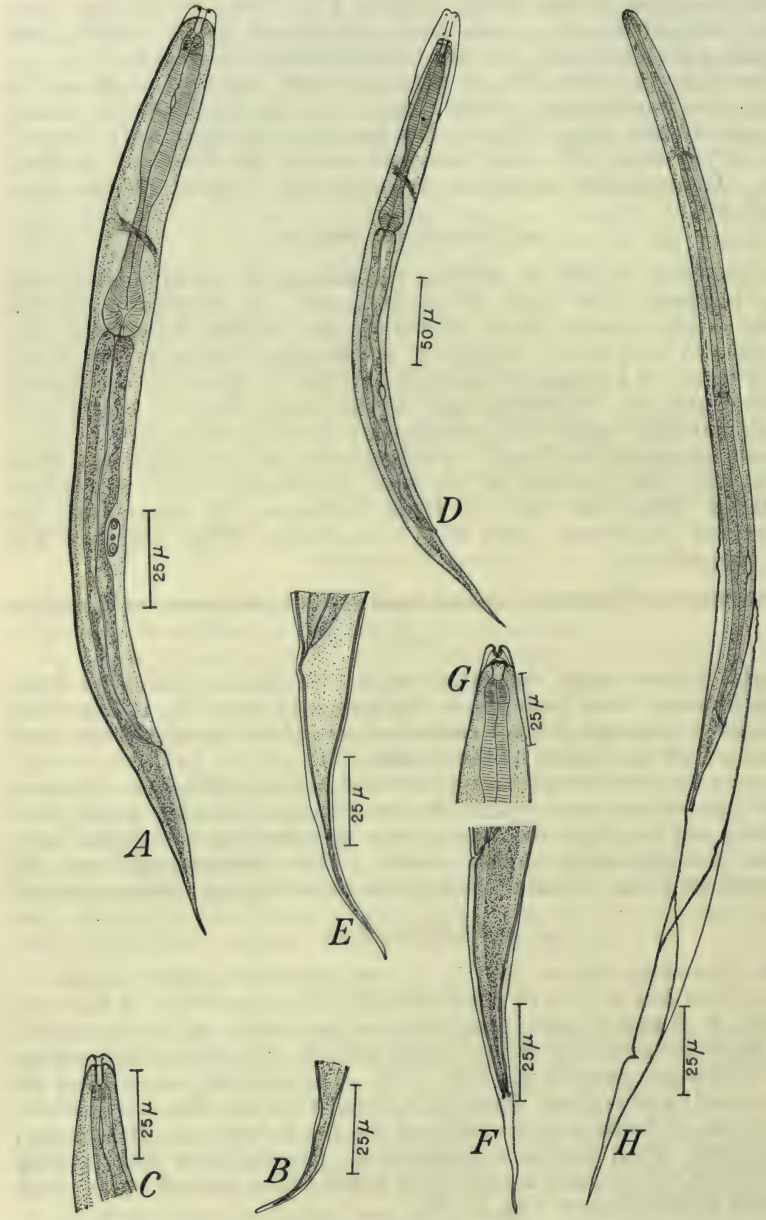

FIGURE 3.—Various stages in the development of strongyliform larvae of *Strongyloides ransomi* (indirect cycle): *A*, First-stage larva (newly hatched); *B*, posterior end of first-stage larva during early first ecdysis; *C*, anterior end of first-stage larva; *D*, second-stage larva immediately following first molt; *E*, posterior end of second-stage larva showing disintegration of tip of tail; *F*, posterior end of a more advanced second-stage larva; *G*, anterior end of second-stage larva during second ecdysis; *H*, strongyliform larva undergoing second molt.

transition (fig. 3, *E*, *F*, and *G*). When the complete strongyliform morphology has been attained, the second molt occurs. In water culture the larvae tend to be somewhat dwarfed in size. A larva only 460μ long was observed in the act of shedding the skin in this medium (fig. 3, *H*).

THIRD-STAGE OR INFECTIVE LARVAE

The strongyliform larvae of the indirect cycle of development are morphologically indistinguishable from those which develop directly from the eggs of the parasitic female. Incubation of feces cultures at room temperature for from 6 to 8 days is ordinarily necessary before all the larvae of the indirect cycle of development attain the infective state. Infective larvae obtained from the eggs of free-living females cultured in water required from 48 to 60 hours for their development.

PATHS OF ENTRY OF INFECTIVE LARVAE INTO HOST

The ability of infective larvae of several species of *Strongyloides* to penetrate the skin of normal and other hosts has been repeatedly demonstrated and is so well known to parasitologists that a review of the extensive literature on this subject is unnecessary. That infection may occur by the oral route is also well known. Fülleborn (*2*), however, has reported that when larvae of *S. stercoralis* are administered to dogs by mouth the vast majority of the larvae are killed by the digestive juices, and that infection occurs only by virtue of the fact that a few of the larvae bore into the stomach wall, pass to the lungs by way of the portal system, and return by way of the trachea and esophagus to the intestine where they develop to maturity. Mönnig (*17*) has reported, on the other hand, that sheep normally become infected with *S. papillosus* by the oral route and that infective larvae of this species are rather poor skin penetrators. Mönnig states also that larvae administered by mouth apparently do not migrate to the lungs. Because of the wide difference of opinion which exists as to the facility with which *Strongyloides* larvae of different species penetrate the skin or establish themselves in the intestine following ingestion, it seemed appropriate to investigate the facts with reference to *S. ransomi*. In view of the facts brought to light also by Looss (*13*) and Fülleborn (*2*) concerning the migration of *Strongyloides* larvae following percutaneous infection, the lungs of all experimental animals so infected were examined.

PENETRATION OF SKIN

In accordance with the technic described by Goodey (*7*), the freshly excised skin of a 3-day-old rat was stretched, hair upward, on a circular cork ring floated in a small glass dish containing physiologic saline solution warmed to a temperature of 37° C., and maintained at this temperature in the incubator. A drop of water containing 400 infective larvae was placed on the rat skin. The water evaporated completely in 15 minutes; 1 hour thereafter the salt solution was removed, centrifuged, and examined. Three larvae were found in it. Sections of the skin prepared in the usual manner were microscopically examined for larvae with negative results.

A second experiment was performed in the same manner. Forty-five minutes were required for the evaporation of the drop of water, which contained 950 larvae. One-half hour later the salt solution was examined and 5 larvae were found in it. The area of skin upon which the larvae had been placed was fixed in hot 70-percent alcohol. The epithelial layer was mechanically removed and cleared in an alcohol-phenol mixture. Microscopic examination showed numerous larvae lying in a horizontal position on the surface of the skin, but none appeared to have penetrated. The dermal layer was stained and sectioned; examination failed to reveal the presence of larvae in this layer.

Thus less than 1 percent of the larvae placed on rat skin in these two experiments were subsequently found in the salt solution, and none were found in the skin sections examined microscopically.

Infective larvae suspended in a few drops of water were applied to the skin of 5 pigs, 1 rabbit, and 2 guinea pigs. After the water had evaporated from the skin, a period of drying, which ranged from 10 to 180 minutes, was allowed. Usually the skin area was then washed with water or soap and water and was wiped off with absorbent cotton. In most cases 70-percent alcohol was also used to wash the skin. After the skin area had been washed, a further period of drying was allowed before the animal was returned to its cage. Control animals were not used, since fecal examinations or post-mortem findings were deemed adequate proof, under the conditions of the experiments, as to the occurrence or nonoccurrence of penetration. In the case of the pigs, the preliminary fecal examinations were made by a modification of the Lane technic. Following is an account of the experiments involving the rabbit and the guinea pigs:

Since natural infestations with *Strongyloides* do not occur in laboratory-raised rabbits, a preliminary examination of the feces of rabbit 2 was omitted. On May 4, 6, and 10, respectively, a few drops of water, in which a very large number of infective larvae of *S. ransomi* were suspended, were placed on separate shaved areas of the skin of this animal. On May 13 the rabbit was killed. The contents of the small intestine were flushed out with warm water, and several adults and numerous larvae of *S. ransomi* were recovered. The larvae ranged from 525μ to 2.5 mm in length. The lungs were cut up and placed in the Baermann apparatus. Twenty strongyliform larvae of *S. ransomi* were recovered from these organs in this way.

A large number of larvae suspended in a small quantity of water were placed on a shaved area of the skin of guinea pig 1 on April 29. The animal was killed on May 1, and this area of skin was excised and examined. Several living larvae were found in the skin and subcutaneous tissue. In a similar manner, large numbers of infective larvae were applied to the skin of guinea pig 2 on May 3 and 5. The animal was killed on May 8, and several living larvae were found in the skin and subcutaneous tissue which was excised from the areas where larvae had been applied. No larvae were recovered from the lungs or small intestine of either of these two guinea pigs.

TABLE 1.—*Results of skin-penetration experiments with Strongyloides ransomi larvae on 5 pigs*

Pig no.	Age	Results of preliminary fecal examinations by modification of Lane technic	Date of application of larvae to skin	Larvae applied	Ante-mortem evidence of infection (microscopic examination of feces)	Date of first appearance of eggs in feces	Date of post-mortem examination	Results of post-mortem examination of—	
								Small intestine	Lungs
	Weeks			*Number*					
2-A	20	Few *Strongyloides* eggs present.	Nov. 11	14,000	Increase in egg count.	(1)	Jan. 3	Several mature and immature adults; several strongyliform larvae 500μ to 600μ long.	No larvae.
			Dec. 9	18,500					
			Dec. 22	5,000					
			Dec. 30	8,500					
3	8	Negative to repeated examinations.	Jan. 25	3,000	Eggs found [2]	Feb. 2	Mar. 14	Several adults; numerous larvae 550μ to 2.5 mm long.	Several strongyliform larvae.
			Mar. 7	25,000					
			Mar. 11	38,000					
4	10	do	Mar. 18	16,000	do.[3]	Mar. 26	Mar. 27	No adults found, but numerous eggs present; several larvae 500μ to 2.5 mm long.	Several strongyliform larvae; 1 from trachea.
			Mar. 20	26,000					
			Mar. 22	28,000					
			Mar. 24	19,000					
			Mar. 25	17,000					
			Mar. 26	10,000					
5	10	do	Mar. 18	16,000	do.[3]	Mar. 26	(4)		
6	15	do	Apr. 24	11,500	None [5]		Apr. 28	No adults or larvae	1 strongyliform larva.
			Apr. 25	20,000					
			Apr. 26	34,000					
			Apr. 27	24,000					

[1] Undetermined.
[2] Feces examined by the salt flotation method.
[3] Feces examined by a modification of the Lane technic.
[4] This animal was not killed during the experiment. See data in table 2.
[5] This pig was killed on the fourth day following the first application of larvae to the skin.

The results of the experiments involving the five pigs are given in table 1. The data in the table are supplemented by figure 4, which is a graphic presentation of egg counts obtained on samples of feces from one of the pigs, no. 2–A.

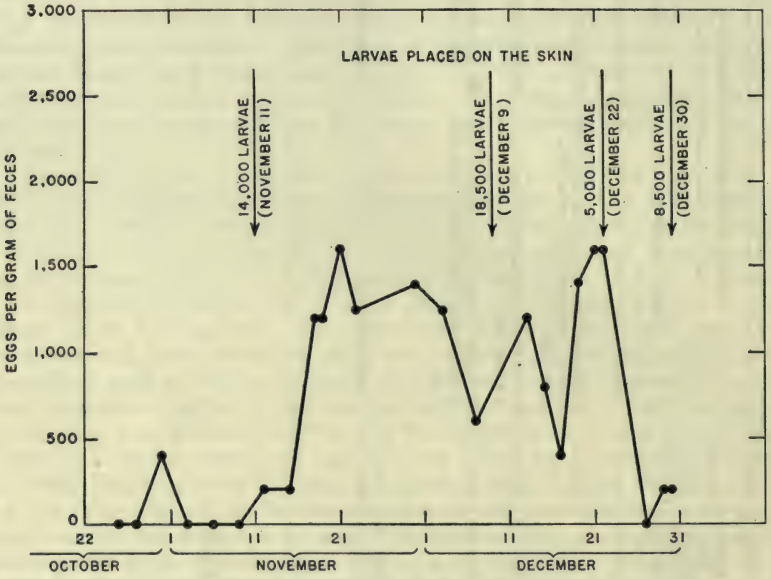

FIGURE 4.—Egg counts obtained on samples of feces from pig 2–A exposed to infection, as indicated, during the period October 26 to December 30.

The data given show that infective larvae of *S. ransomi* were capable of penetrating the skin of pigs and a rabbit, and that intestinal infestations resulted from the percutaneous entry of the larvae in all cases except that of pig 6, in which animal one larva was found in the lungs. The larvae also penetrated beneath the skin of two guinea pigs, but had not reached the lungs or intestine of guinea pig 2, 5 days after the first infection.

INFECTION BY ORAL ROUTE

Experiments on infection by the oral route involved 5 pigs, 1 of which was a control, and 1 rabbit. An account of the experiment with the rabbit follows:

Rabbit 1, a laboratory-raised animal, was given large oral doses of infective larvae of *Strongyloides ransomi* on April 27 and 29. On post-mortem examination May 3, the sixth day following the first administration of larvae, the animal was found to harbor adult and larval *S. ransomi* in its small intestine. The lungs were finely cut up with a scissors. Examination by means of the Baermann apparatus did not reveal the presence of larvae.

The experiments involving the pigs are summarized in table 2. Pig 5 is the same animal which was subjected to a single percutaneous

TABLE 2.—*Results of administering Strongyloides ransomi larvae orally to pigs*

Pig no.	Age	Results of preliminary fecal examinations by Lane technic or egg count	Date of administrations of infective larvae	Larvae fed	Ante-mortem evidence of infection (micropscopic examination of feces)	Date of first appearance of eggs in feces	Date of post-mortem examination	Results of post-mortem examination of—	
								Small intestine	Lungs
	Weeks			*Number*					
1–A	22	No eggs	Dec. 21	5,000	None; egg count remained zero		Jan. 22	1 adult	No larvae found.
			Jan. 5	11,000					
			Jan. 9	3,400					
			Jan. 17	6,600					
			Jan. 19	7,700					
			Jan. 20	1,000					
1–B	5	do	(2)	0	None [3]		(1)		
2–B	5	do	Mar. 15	2,900	Eggs found [3]	Mar. 22	(1)		
3–B	5	do	do	5,000	do [3]	Mar. 21	Apr. 11	12 adults	(4).
5	13	do	Apr. 6	23,000	do [3]	Apr. 13	Apr. 30	More than 250 adults	(4).

[1] Animal not killed.
[2] This animal was a control; consequently, no larvae were administered.
[3] Feces examined by the salt flotation method.
[4] Not examined.

infection. Although the feces of this pig were positive for eggs of *S. ransomi* on the eighth day following infection by the percutaneous route, subsequent examinations failed to reveal the presence of eggs in the feces. Pig 1–A had been given by mouth 5,600 larvae of *S. papillosus* on October 25 of the preceding year, and 9,500 larvae of this species were placed on its skin on October 26. During the following 8 weeks, 20 egg counts on the feces of this pig were made, no eggs being found. However, the failure of *S. papillosus* to develop in this animal, as judged by the subsequent failure to find eggs by the Stoll egg-counting method, is rendered inconclusive by the fact that the egg production remained zero despite repeated feedings of infective larvae of *S. ransomi*.

The data given indicate that the four pigs to which larvae were fed and the rabbit acquired infestation following the administration by the oral route of infective larvae of *S. ransomi*, as indicated by the appearance of eggs in the feces or by the post-mortem finding of adults of this species. Eggs appeared in the feces of pigs 3–B and 2–B on the sixth and seventh days, respectively, following the feeding of larvae. Pig 1–A was almost entirely resistant to infestation. Eggs appeared in the feces of pig 5 on the seventh day after infection. The feces of the control pig 1–B were repeatedly examined and remained negative for helminth eggs.

DEVELOPMENT OF STRONGYLOIDES RANSOMI IN NORMAL AND OTHER HOSTS

IN LUNGS AND SKIN

Larvae were recovered from the lungs of pigs 3, 4, and 6 and rabbit 2. The dates of percutaneous administrations of larvae to these animals and the dates of the respective necropsies have been previously given. The larvae from the lungs were morphologically similar to infective third-stage larvae except for slightly greater thickness, greater length and width of the genital primordium, slightly more pronounced striation of the cuticle, and the greater prominence of the nerve ring and its associated structures (fig. 5, A). Measurements obtained from 2 larvae from the lungs and 1 from the trachea of pig 4 appear in table 3. The tails of all larvae obtained from the lungs were notched as in preparasitic third-stage larvae. None of the larvae from the lungs of the pigs or rabbit were undergoing a molt or showed any evidence of the approach of a molt.

TABLE 3.—*Principal measurements (in microns) of representative parasitic larvae of Strongyloides ransomi found in pigs and a rabbit*

Measurement	Pigs							Rabbit intestine (2 larvae)	
	Lungs (2 larvae)		Trachea (1 larva)	Intestine (4 larvae)					
Length	507	540	555	470	555	483	530	725	2,650
Width in region of esophagus	20	22	26	21	25	18	24	22	48
Distance from nerve ring to anterior end	120	89	91	63	80	93	80	112	247
Length of esophagus	290	250	260	277	275	272	275	345	648
Length of genital primordium	19	17	20	14	28	17	15	43	------
Length of tail	60	72	62	58	66	66	63	73	70

Some of the larvae removed from the skin and subcutaneous tissue of guinea pig 2, 5 days after the animal was subjected to a percutaneous infection, had become slightly modified in morphology as compared with free-living infective third-stage larvae. The genital primordium had increased in size, particularly in width, and the larvae resembled those found in the lungs of pigs. None of the larvae from the skin of this guinea pig, removed 3 and 5 days, respectively, after 2 infections, nor from the skin of guinea pig 1, 2 days after infection, were undergoing a molt or showed evidence of the approach of a molt.

IN SMALL INTESTINE

The smallest and morphologically least advanced larvae (fig. 5, *B*) recovered from the small intestines of the above-mentioned pigs and rabbit and also from the intestine of pig 2–A were indistinguishable from the larvae obtained from the lungs. The tail presented the notched appearance characteristic of third-stage larvae. Four of the smallest larvae found in the intestines of percutaneously infected pigs showed the size relationships given in table 3. In specimens of about this size, the distance from the genital primordium to the anus was found to be noticeably greater than the distance from the primordium to the bulb of the esophagus. About four cells were visible in the primordium at this stage. Morphologically similar larvae were found in the small intestine of rabbit 1, which was given infective larvae by mouth 4 and 6 days, respectively, previous to necropsy.

The structure of a somewhat larger larva from the intestine of rabbit 2 indicated that the first changes which appear, as growth takes place, are a further increase in the size of the genital primordium and a multiplication of the number of cells within it. Measurements obtained from this larva are given in the next to the last column of table 3. It is noteworthy that the tail of this larva was still notched at the tip. A slightly larger larva was found in which the tail was beginning to undergo the transition in shape from a notched tip to the rounded tip found in more advanced larvae. Slight separation of the cuticle had occurred at the tip of the tail and the tip of the sheath was definitely notched, the loss of the notched-tail termination evidently occurring at the very commencement of the final ecdysis.

Numerous larvae from 900μ to 2.5 mm long were removed from the intestines of pigs and rabbits following either percutaneous or oral entry of the larvae. Larvae about 1 mm long exhibited the beginning of the formation of the vulva and vagina. The genital primordium was seen, in lateral view, to have extended both posteriorly and anteriorly from the primordium of the vulva, and was also visible anteriorly in a position dorsal to the intestine (fig. 5, *C*). The formation of the vulva is well indicated before the ovaries are recognizable as such. Larvae about 1.5 mm long showed the reflection of the primordium anteriorly and posteriorly (fig. 5, *D*). All larvae falling within the size range mentioned above exhibited a progressive separation of the cuticle from the body. Especial

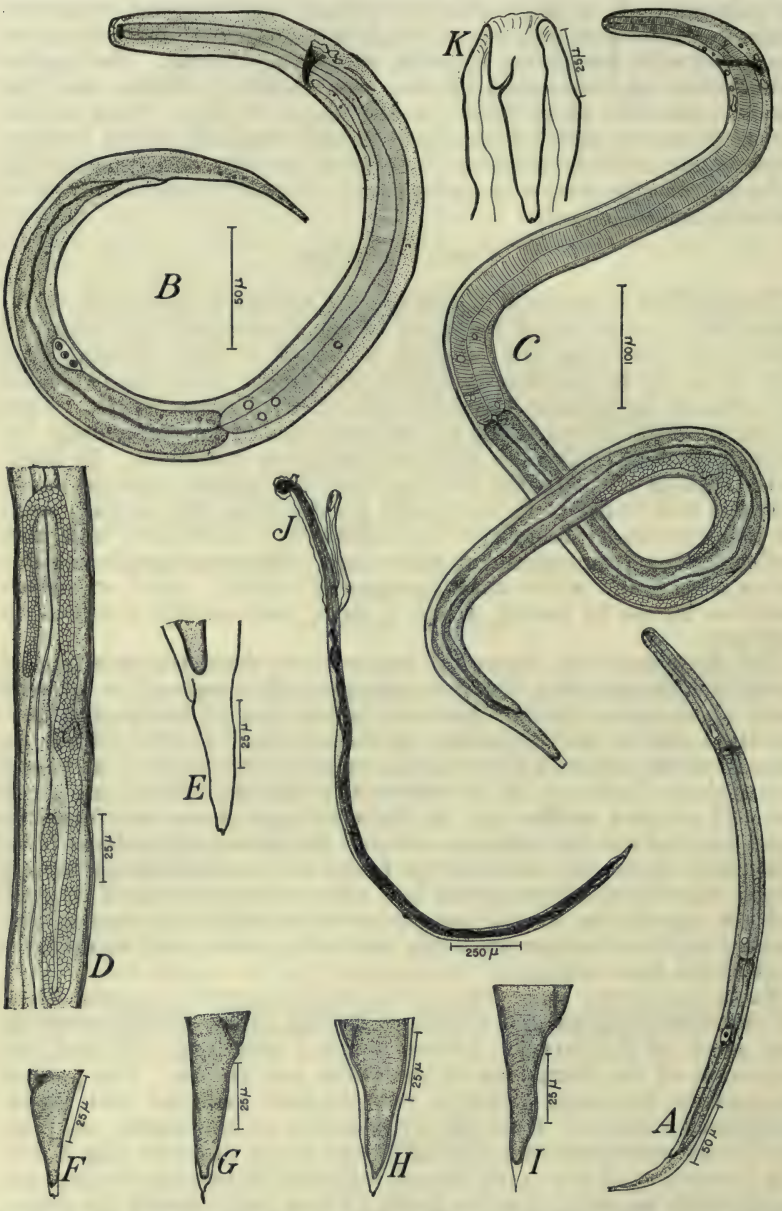

FIGURE 5.—Various stages in the parasitic development of *Strongyloides ransomi*: *A*, Strongyliform larva from lungs of a pig about 3 days after percutaneous infection; *B*, larva from small intestine of pig about 4 days after percutaneous infection; *C*, larva from intestine of pig during early final ecdysis; *D*, vulvar region of more advanced larva from intestine of pig; *E* to *I*, posterior ends of larvae during final ecdysis, showing variation in shape of tip of sheath; *J*, preadult female from intestine of rabbit 6 days after percutaneous infection, undergoing final molt; *K*, posterior end of cast sheath of final molt.

attention was given to a study of the shape of the posterior tip of the sheath, and although much variation was noted, owing possibly to some extent to the pressure of the coverslip but also unquestionably to normal variation, the tip was found to be definitely notched in many instances. In some cases the tip of the sheath appeared to terminate in three processes or evaginations, whereas in other specimens it tapered to a rather sharp point. The variations found are illustrated in figure 5, *E* to *I*. In all these larvae the shape of the tail resembled that of the adult female.

Larvae which had attained a length of about 2.5 mm were found to have attained the morphology of the adult female. Individuals of this size were found which were enveloped in the sheath of the final molt or to which the cast-off cuticle still adhered. A larva (fig. 5, *J*) from the intestine of rabbit 1, which was in the act of casting the final cuticle, had the measurements shown in the last column of table 3. Additional measurements of this larva were: Distance from vulva to anterior end, 1,660μ; distance from vulva to posterior end, 938μ; width in region of vulva, 49μ. The posterior tip of the sheath of this specimen was notched, as illustrated in figure 5, *K*.

DISCUSSION OF PREPARASITIC AND PARASITIC DEVELOPMENT OF STRONGYLOIDES RANSOMI

The writer's observations, indicating that two molts occur in the development of strongyliform infective larvae from the eggs of parasitic or " rhabditiform " females of *Strongyloides ransomi*, are in agreement with those of Looss (*14*, *15*), who, for certain other species of *Strongyloides*, including *S. stercoralis*, reported two molts in the course of the development of filariform (i.e., strongyliform) larvae of the direct and indirect cycles. The writer's results are at variance with the reports of Grassi and Parona (*8*), Perroncito (*18*), Leuckart (*12*), Grassi and Segrè (*9*), Golgi and Monti (*5*), Zinn (*27*), Leichtenstern (*11*), Gonder (*6*), and Kreis (*10*), who mention only one molt during the course of the development of filariform larvae of *S. stercoralis* and other species. Four molts have been described by the writer in the course of the development of " rhabditiform " unisexual adults from the eggs of the parasitic female of *S. ransomi*. This is in disagreement with the findings of Looss (*15*) and other investigators of the life history of *S. stercoralis*, all of whom observed only one molt (i.e., the final molt) in the development of free-living adults.

Third-stage larvae of *S. ransomi* which gain entry to the body of the host, either through the oral or percutaneous route, have been observed to molt once in the intestine of the host animal. This molt occurs about 6 days after infection, when the larvae have attained the morphology of the adult female. As has been mentioned, when the larvae first arrive in the intestine they differ from free-living infective larvae only in minor particulars, and still possess a notched tail. Moreover, the posterior tip of the sheath of molting larvae in progressive states of development is usually also definitely notched. These facts are a strong indication that the entire development from the smallest larvae found in the intestine to the adult form occurs in

connection with but one molt. It cannot, however, be concluded with certainty that only one molt occurs during the parasitic development of *S. ransomi*, since it is possible that following percutaneous entry to the host the larvae may molt while they are in the lungs. However, none of the larvae recovered from the lungs of experimental animals were molting. None of the larvae removed from beneath the skin of a guinea pig showed evidence of a molt, despite the fact that some of these larvae had undergone morphological advancement comparable to that attained by larvae during their passage through the lungs. In the case of orally infected animals no evidence of the occurrence of an earlier molt was discovered.

In this connection, it is of interest that only one molt in the course of the parasitic development of *Strongyloides* was reported by Looss (*15*) who, on the basis of observations on the development of three unnamed species, one of which unquestionably was *S. stercoralis*, states that filariform (i.e., strongyliform) larvae cast their skins a third time and thereby assume the adult condition. Fülleborn (*2*), on the other hand, apparently considers that two molts occur in the development of *S. stercoralis* in dogs, the larvae concerned having been removed by him from the trachea of the host. Although the occurrence of two molts in the lungs seems rather unusual in the development of an intestinal helminth, Fülleborn's discovery that *S. stercoralis* can reach sexual maturity in the trachea of dogs may explain this finding. It is of further interest that Fülleborn (*4*) found that infective *S. stercoralis* larvae maintained beneath the skin of rabbits from 6 to 17 days could attain a structure comparable to that usually reached in 3 or 4 days by larvae in the trachea, but he presents no information as to whether a molt accompanied the attainment of this more advanced developmental stage.

While with respect to paths of entry and migration within the body, it cannot be definitely stated that strongyliform larvae of *S. ransomi* do not migrate to the lungs following entry into the body of the host by the oral route, the available evidence is negative. No larvae were found in the lungs of a pig and a rabbit to which oral infections had been given 2 and 4 days, respectively, previous to autopsy. Significant infestations were readily produced in pigs and rabbits by either the percutaneous or oral route; hence it must be concluded, on the basis of the experiments performed, that both modes of infection take place and are of importance in nature.

EFFECTS OF ENVIRONMENTAL FACTORS ON VIABILITY OF EGGS AND SURVIVAL OF LARVAE

EFFECT OF COLD ON EGGS

Freshly prepared cultures from the feces of pigs infested with *Strongyloides ransomi* were subjected to low temperatures for various periods, and the effects were studied in a number of experiments. The cultures were contained in Petri dishes and following the desired exposure to cold were examined after they had incubated for a suitable time at room temperature to permit infective larvae to develop from any eggs which might have been able to withstand the exposure. The amount of moisture in the cultures and the proportion of charcoal to feces, when charcoal was employed, were so regulated as

to provide optimum conditions for development. In each experiment a control culture was used. This was prepared in the same manner from the same fecal sample as the experimental culture, but was kept at room temperature. In all cases the control cultures yielded very large numbers of infective larvae when examined after incubation for periods of from 7 to 9 days.

The data relating to the cultures which were subjected to low temperatures are given in table 4.

TABLE 4.—*Effects of low temperatures on viability of eggs of Strongyloides ransomi in types of cultures indicated*

Experiment no.	Nature of culture	Temperature at which culture was exposed	Duration of exposure	Duration of subsequent incubation at 20°–24° C.	Infective larvae found in culture upon examination
		° *C.*	*Hours*	*Days*	
1	Feces [1] and charcoal	−4 to −8	168	9	None.
2	do.[2]	−4 to −8	46	6	Do.
3	do.[2]	−4 to −8	27	7	Few.
4	do.[2]	−4 to −8	24	4	None.
5	Moist feces [2]	−4 to −8	46	6	Do.
6	do.[4]	−4 to −8	23	8	Few.
7	Feces [3] and charcoal	2 to 6	147	5	None.
8	do.[4]	2 to 6	48	7	Several.
9	Moist feces [4]	2 to 6	50	5	None.

[1] Feces were 24-hour accumulation from 2 infested pigs in outdoor pen in December; no preinfective larvae present.
[2] Feces were 24-hour accumulation from 1 infested pig in animal room at about 24° C; not examined for preinfective larvae.
[3] Freshly voided feces; no preinfective larvae present.
[4] Freshly voided feces; not examined for preinfective larvae.

The data given in table 4 indicate that two cultures kept at temperatures from −4° to −8° C. for approximately 24 hours yielded few larvae when examined after subsequent incubation of the cultures for a suitable time at room temperature. In one case no larvae were found in a culture subjected to similar treatment. Each of two cultures exposed to this range of temperatures for 46 hours failed to yield larvae subsequently, as did also one culture exposed for 168 hours. Of two cultures exposed for about 48 hours to temperatures slightly above freezing, only one subsequently yielded infective larvae. A culture kept at these temperatures for 147 hours did not yield larvae when examined after incubation at room temperature. The time required to effect equivalent inhibition or the total suppression of larval development by brief exposures to low temperatures was independent of the composition of the two types of cultures used.

EFFECT OF COLD ON INFECTIVE LARVAE

The effect of low temperatures on the survival of infective larvae was studied according to the procedure used by Alicata (*1*) with larvae of *Obeliscoides cuniculi*. Larvae were placed upon moist charcoal contained in small stoppered glass vials which were placed in an electric refrigerator. One group of vials was kept for various periods at subfreezing temperatures, whereas a second group was kept at temperatures slightly above freezing. After a given exposure, the vials were permitted to remain at room temperature for

an hour or more before examination was made by repeatedly washing the charcoal with water and removing the wash water to a small dish prepared to facilitate the counts of living and dead larvae. In this way the vast majority of the larvae placed in the vials were recovered.

Infective larvae of *Strongyloides ransomi* do not lend themselves well to this type of experimentation, since under optimum conditions deaths continually occur, and the larvae do not live in cultures at room temperatures much longer than 3 weeks. Thus many of the larvae placed in similar vials kept at room temperature as controls died during the experiments. Six experiments were performed at subfreezing temperatures. A majority of the larvae from the control vial for experiment 1 were still alive after 190 hours; about 40 percent of the larvae from the control vial for experiment 5 were alive after 45 hours; and many of the larvae in the two control vials for experiment 6 were still alive after 262 hours. Control vials were not prepared for experiments 2, 3, and 4. The data pertaining to the experiments at subfreezing temperatures are summarized in table 5.

TABLE 5.—*Effect of subfreezing temperatures on survival of infective larvae of Strongyloides ransomi*

Experiment no.	Vial no.	Larvae used	Duration of exposure at −4° to −8° C.	Duration of subsequent maintenance at room temperature		Larvae recovered alive
		Number	*Hours*	*Hours*	*Minutes*	*Percent*
1	1	500	17	1		0
1	2	500	40	1		0
2	3	500	6	1	15	10.0
3	4	1,000	17	2		5.5
3	5	1,000	17	2		2.8
4	6	1,000	26	2		3.4
4	7	1,000	41	2		.4
5	8	1,000	18	2	15	1.6
5	9	1,000	41	2	15	0
6	10	1,000	12	2	15	12.0

Examination of table 5 shows that from 88 to 100 percent of the larvae recovered from the vials after exposure to temperatures from −4° to −8° C. for periods ranging from 6 to 26 hours were dead. About 40 hours' exposure to these temperatures killed all the larvae recovered from 2 preparations, and 99.6 percent of those from a third preparation.

Owing to the inconsistent behavior of larvae maintained at room temperature as controls, a detailed account of the results of tests made at temperatures from 2° to 6° C. is omitted. From 12 to 24 percent of the larvae recovered from vials exposed from 64 to 116 hours at this range of temperature showed evidence of life. A few larvae were feebly active in a preparation exposed to these temperatures for 185 hours.

EFFECT OF DIRECT SUNLIGHT ON INFECTIVE LARVAE

To test the effect of direct sunlight, 750 active infective larvae, suspended in water, were placed in a shallow dish out of doors on a brownish background in such a way that direct rays of the sun reached the larvae without first passing through glass. Under these conditions the larvae were exposed to December sunlight for 15

minutes at a temperature of 9° C. Immediate examination revealed most of the larvae to be slightly active. The preparation was subjected to a further 15 minutes' exposure to sunlight, making a total exposure of 30 minutes. Immediate examination revealed that 180 larvae were slightly motile; 1½ hours later, during which time the larvae were kept at room temperature, 50 larvae were feebly motile. The remaining larvae appeared to be dead.

In a second test, 500 larvae were similarly exposed to sunlight on the same day at a temperature of 6° C. for 45 minutes. Immediate examination showed but 1 larva to be slightly active; 1½ hours later, during which time the larvae were kept at room temperature, 3 larvae exhibited feeble motility. Since the remaining larvae did not revive, it was concluded that they were killed by sunlight.

As a control on the effect of brief exposure to the temperatures mentioned, a similar glass dish containing larvae suspended in water was placed in the electric refrigerator for 30 minutes at 6° C. Immediate examination showed most of the larvae to be inactive. However, after a brief period at room temperature, it was found that the vast majority of the larvae regained their normal activity.

Since in the above experiments a few larvae survived exposure to sunlight for 45 minutes another experiment was later performed. A water suspension of 250 active larvae was placed in each of 4 shallow dishes. The larvae contained in 3 of the dishes were exposed to direct April sunlight at a temperature of from 29° to 30° C. for the intervals shown in table 6. Water of this temperature was added to the dishes from time to time to compensate for evaporation. The fourth preparation was kept in the shade in the laboratory as a control. When examined after 2 hours, the vast majority of the larvae in the control dish showed normal activity.

TABLE 6.—*Results of exposure of 250 Strongyloides ransomi larvae to direct April sunlight, at a temperature of 29°–30° C.*

Time of exposure (minutes)	Larvae active—	
	On immediate examination	1 hour later
	Number	*Number*
15	239	237
30	220	100
60	0	0

From the data presented, it may be concluded that infective larvae of *Strongyloides ransomi* exposed to direct sunlight at nonlethal temperatures are killed in from 45 to 60 minutes of exposure.

EFFECT OF DESICCATION ON INFECTIVE LARVAE

A drop of water containing a small number of active larvae was placed on each of 11 glass slides. The contents of the slides were permitted to dry in air at room temperature, and the instant at which complete evaporation of the water occurrred, as determined by examination under a binocular microscope, was noted. When the desired air desiccation was accomplished, a drop of water was placed

on each slide in the area where the larvae were present, and the subsequent behavior of the larvae was noted, as indicated in table 7. Larvae from two similarly prepared cultures were used in making the test.

TABLE 7.—*Effect of desiccation, in air (temperature 24° C.), on infective Strongyloides ransomi larvae*

Culture and slide no.	Larvae used	Period of desiccation	Larvae active, after addition of water, at expiration of—		
			10 minutes	30 minutes	60 minutes
Culture 1:	*Number*	*Minutes*	*Number*	*Number*	*Number*
1	25	3	12	16	[1] 11
2	23	7	5	7	[1] 3
3	35	10	0	0	0
4	21	12	0	0	0
5	20	14	0	0	0
Culture 2:					
1-A	31	2	27	[1] 27	
2-A	35	3	7	[1] 12	
3-A	30	4	0	[1] 6	
4-A	37	5	0	[1] 8	
5-A	31	8	0	[1] 3	
6-A	32	9	0	[1] 0	

[1] Heat applied to determine vitality of larvae.

The results given in table 7 warrant the conclusion that infective larvae of *Strongyloides ransomi*, present on a nonabsorptive surface, are killed by 9 or 10 minutes of air drying at room temperature. Under these conditions many larvae are killed or their vitality is impaired by an exposure of from 3 to 5 minutes.

EFFECT OF CHEMICALS ON INFECTIVE LARVAE

Larvae were transferred, by means of a wire loop, from clusters present on a Petri-dish lid into a drop of the desired chemical solution, and viewed through a binocular microscope in order to note the time when all the larvae became inactive. Under these conditions, larvae were rendered instantaneously inactive in 95- and 70-percent alcohol. The drop was greatly diluted with water, but only a few larvae had revived an hour later. On other occasions it was noted, in agreement with the findings of Fülleborn (*2*), that a large percentage of the larvae, contained in a drop of water, which had been rendered inactive by their introduction into 70-percent alcohol, regained normal activity when the alcohol was greatly diluted.

Larvae also were introduced into 1-percent copper sulphate solution. A few were able to survive for 30 minutes or more, but most of them were killed within 30 minutes.

The majority of larvae introduced into a drop of 1-percent phenol solution were immediately killed, although a few larvae showed total cessation of activity only after 9 minutes of exposure to this chemical. Subsequently the drop was greatly diluted, but none of the larvae revived during the ensuing 18 hours.

An ordinary cresol disinfectant, in the concentration recommended for the spraying of outbuildings, killed the larvae quickly. All larvae ceased movement within 2½ minutes after their introduction into this chemical solution, and none revived during the ensuing 18 hours despite great dilution with water.

REACTIONS OF INFECTIVE LARVAE TO STIMULI AND ENVIRONMENT

REACTION TO HEAT

A number of larvae were placed in water contained in a shallow glass dish. A fairly equal distribution of the larvae in the dish was effected in such a manner that none were visible in a particular field of a binocular microscope, when the dish was so placed on the microscope stage that its center was above the aperture in the center of the stage. A warmed glass rod was applied to the bottom of the dish in the center of the field. In a few moments larvae were seen migrating from the periphery toward the source of heat, and a considerable number soon became concentrated at the point where the rod had been applied. The experiment was repeated with similar results.

It may, therefore, be concluded that infective larvae of *Strongyloides ransomi* are attracted to a source of moderate heat. Larvae present on a glass slide are stimulated to great activity when heat is applied to the under surface of the slide. Apparently very slight changes in temperature are detected by the larvae, since the proximity of a finger to a slide is sufficient quickly to cause movement of the larvae present in a drop of water on the slide toward this source of heat.

REACTION TO STRONG ARTIFICIAL LIGHT

The water contained in a small glass dish was agitated to produce an equal distribution of about 500 larvae present. The dish was placed on the stage of a binocular microscope in such a manner that one-half of the bottom of the dish was shaded by a black background impermeable to light. The same portion of the top and sides was shaded with black paper. A strong beam of light from a covered and shaded microscope lamp in a dark room was reflected by the microscope mirror through the unshaded half of the dish. After 30 minutes' exposure to the light, it was found that 115 larvae were present in the unshaded half of the dish and 383 in the shaded half.

In an essentially similar experiment a 100-watt electric lamp was used as a source of light. It was placed in front of and above the dish, arranged as before, at a distance of 4 inches from the center of the latter. Thermometers indicated a differential of less than 1° C. in the temperature at the shaded and unshaded sides of the dish. The contents of the dish were agitated as before. Examination after 10 minutes' exposure to the light showed that the vast majority of the larvae were present in the shaded half of the dish. It may, therefore, be concluded that infective larvae of *Strongyloides ransomi* avoid strong artificial light.

REACTION TO DIFFUSE DAYLIGHT

One-half of a Petri dish, including the cover, sides, and bottom, was painted with two coats of india ink. A large number of infective larvae, rather equally distributed in water, were put in the dish, which was so placed on a black background that diffuse daylight from northern and eastern windows reached it. Two hours later

the majority of the larvae were present in the unshaded portion of the dish.

Except for a small circular area in the center of the cover and bottom, a Petri dish was entirely painted with two coats of india ink. A homogeneous suspension of larvae in water was introduced into the assembled dish, which was so placed on the stage of a binocular microscope that the central unshaded area of the cover and bottom was directly above a small aperture in the center of the stage. This arrangement permitted the passage of a beam of diffuse daylight from the microscope mirror through the small unshaded central area of the dish. The approximate number of larvae visible in the low-power field was noted. Fifteen minutes later a noticeable increase in the number of larvae visible had occurred, and within 45 minutes the visible larvae were so numerous that they could not be counted with accuracy. This experiment was repeated by substituting a much less concentrated suspension of larvae. Seventy larvae were visible in the field at the beginning of the experiment. After 30 minutes, the visible larvae were too numerous to permit an accurate count. It is evident that infective larvae of *Strongyloides ransomi* respond positively to diffuse daylight.

REACTION TO EXCLUSION OF AIR

Fülleborn (*3*) has shown that larvae of *Strongyloides stercoralis* are somewhat attracted to oxygen and are repelled by carbon dioxide. He showed that larvae rendered inactive through the exclusion of oxygen from their environment by means of an atmosphere of hydrogen revived when air was again made available to them.

A type of behavior, which it is believed may be explained on the basis of Fülleborn's results, has been noted in the case of larvae of *S. ransomi*. A culture containing infective larvae was placed in the Baermann apparatus. About 18 hours later, a few cubic centimeters of liquid was withdrawn from the rubber tube of the apparatus into a shallow dish. Inactive, apparently dead, larvae were present in the fluid. After a few minutes' exposure of the liquid to air, a number of larvae exhibited feeble movements. Air was bubbled through the liquid for a few moments, and immediately a large percentage of the larvae began to move about actively. Apparently the initial inactivity was due to the exclusion of the oxygen of the air from the larvae by the column of water in the Baermann apparatus, which was about 15 inches deep.

MIGRATION

The lid was removed from a Petri dish which contained a rich culture of larvae and was replaced by a clean lid not in contact with the culture. Within 1 hour the new lid was found to harbor so many larvae that they were readily visible to the naked eye. It was noted on repeated occasions that larvae migrated from within culture dishes which provided optimum favorable conditions to the exposed inside surface of the sides or edges of Petri-dish covers, where they gathered in macroscopically visible clusters and where they soon perished as a result of desiccation. Infective larvae of *Strongyloides ransomi* were, therefore, energetic migrants under the conditions described.

CLINICAL SYMPTOMS OF PATHOGENICITY

A special study to determine whether intestinal or pulmonary lesions result in pigs from infection with *Strongyloides ransomi* was not within the scope of the present investigation. However, certain observations, incidental to the experiments performed, were made in connection with the clinical symptomatology produced in the host by this parasite.

It was noted in the case of pigs 3, 4, and 5 that when larvae were placed on the skin there was almost immediate reddening of the skin in the areas where larvae were applied. This reaction took the form of pimplelike eruptions and often involved the hair follicles. After several hours, the eruptions usually became pale and vesicular. In two other pigs no reaction of the skin occurred following the application of larvae to it. In the case of a rabbit, when larvae were applied to the skin, there was no pronounced immediate reaction, but after several hours reddened, scaly, indurated elevations appeared. In guinea pigs, immediate congestion of the skin in areas where larvae were placed was noted. Later indurated elevations appeared.

A few days after the oral administration of larvae to pigs 1–A, 2–B, and 3–B, diarrhea occurred. In pig 3–B, the anus became prolapsed about 10 days after the larvae were given and following a period of rather severe diarrhea. In rabbit 1, to which larvae were administered orally, marked diarrhea, lassitude, and emaciation occurred. Rabbit 2, infected percutaneously, was similarly affected. Pig 5 was given a large oral dose of larvae, and it was noted that, beginning about 16 days later, the fecal pellets were often heavily coated with a foul-smelling mucus, suggesting a catarrhal condition of the intestine. About 1 week later the animal died, and postmortem examination revealed the presence in the small intestine of large numbers of *S. ransomi*. The necropsy showed the animal to be suffering from a pronounced anemia.

It is believed that infection and parasitism with *S. ransomi* were responsible for the conditions which have been described, but other causes cannot be excluded with absolute certainty. There were, however, no changes in diet or other factors, and it is difficult to explain the injury observed as due to anything other than parasitism with *S. ransomi*. The symptoms observed are similar to those noted by European investigators in pigs infested with *Strongyloides*.

SUGGESTIONS FOR THE CONTROL OF THE PARASITE

The following suggestions for the control of *Strongyloides ransomi* are based on experimental data presented in this bulletin.

The McLean swine sanitation system developed by workers in the Bureau of Animal Industry and described by Raffensperger and Connelly (*20*) should be used. Owing to the rapidity with which infective larvae develop directly from the eggs of *S. ransomi* outside the host under favorable conditions, it is essential to keep the farrowing house dry and to remove all litter daily.

In order to take advantage of the destructive effects of drying and sunlight upon the infective larvae, farrowing houses, feeding pens, and watering troughs should be located on well-drained, unshaded areas of soil free from vegetation or debris which might

provide shade or moisture. The lot selected should not have been occupied by swine during the previous 3 months. In addition, to prevent infection with other parasites the lot selected should have had a crop grown on it since its previous occupation by swine, as recommended by Ransom (*21*) under the swine sanitation system for the control of ascarids, and by Spindler (*26*) for the control of kidney worms.

Since the life span of infective *S. ransomi* larvae under laboratory conditions is brief, and presumably would be brief even under favorable natural conditions, and since the larvae are readily killed by subfreezing temperatures, the precautions necessary in the selection of a clean pasture to which pigs may be hauled should be governed in part by these considerations.

SUMMARY AND CONCLUSIONS

Two molts take place in the course of the development from the eggs of the parasitic or free-living females to the infective strongyliform larvae of *Strongyloides ransomi.*

Four molts apparently occur in the course of the development from the egg of the parasitic female to the free-living adult stage.

The infective larvae can infect percutaneously and by the oral route; in the former case the larvae go through the lungs. The larvae can penetrate the skin of rabbits and guinea pigs as well as that of swine. In rabbits the worms have been reared to fertile maturity.

Only one molt has been observed to occur in the course of the development of *S. ransomi* in its normal host and in an experimental host. This molt takes place in the intestine about 6 days after infection.

The development of infective larvae was prevented by exposure of cultures for 46 hours to temperatures from −4° to −8° C.; virtually all infective larvae were killed by an exposure of 40 hours at these temperatures.

Infective larvae are attracted to a source of moderate heat, they avoid strong artificial light, and they are attracted by diffuse daylight. Direct sunlight killed the larvae at nonlethal temperatures in from 45 to 60 minutes.

Air drying for from 3 to 5 minutes at room temperature is fatal to many larvae; an exposure of from 9 to 10 minutes destroys all larvae.

A 1-percent solution of copper sulphate or phenol and an ordinary dilute cresol disinfectant were each destructive to the larvae. Of these, cresol was the most potent and destructive.

Lack of air renders the larvae inactive; activity is renewed by some larvae upon readmission of air within a suitable time.

The larvae migrate actively and may reach situations where, owing to lack of moisture, they perish.

Skin lesions have been observed following the penetration of the larvae into experimental hosts; diarrhea, anemia, and general lassitude are symptoms which may accompany intestinal infestation with *S. ransomi.*

Measures suggested for the control of *S. ransomi* infestation in pigs include thorough sanitation and the selection of a dry, unshaded area as a permanent lot.

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COTTON ROOT ROT AS AFFECTED BY CROP ROTATION AND TILLAGE AT SAN ANTONIO, TEX.

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INTRODUCTION

The cotton root-rot disease is recognized as one of the most destructive plant diseases in Texas (*1, pp. 27–30*).[2] It attacks a wide range of cultivated plants and is particularly destructive to cotton (*17, 18, 19, 20*). The disease is caused by a fungus known as *Phymatotrichum omnivorum* (Shear) Duggar. As the name implies, it attacks the roots of plants, destroys the root tissues, and usually causes the sudden death of the plant. Definite wilting is usually the first observed symptom, a day or two in advance of the death of the plants.

In the San Antonio locality the disease first manifests itself in cotton fields the latter part of May or early in June, depending upon seasonal conditions. The plants are subject to attack until killed by frost. The organism causing this disease remains infectious in

[1] The writer wishes to acknowledge the assistance rendered by I. Milburn Atkins, assistant superintendent, U.S. San Antonio Field Station, 1928–30, who helped materially in a preliminary compilation of data and certain portions of the report.

[2] Italic numbers in parentheses refer to Literature Cited, p. 30.

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the soil from season to season, and many methods of soil management and crop rotation have been recommended as means of its eradication or control (*2*, *6*, *15*, *19*). A series of experiments at the United States San Antonio Field Station, started in 1909 to test the value of various crop sequences and cultural practices in crop production (*11*), has afforded an excellent opportunity for the study of these practices in relation to their effect on the occurrence of cotton root rot. These experiments include 50 different cropping systems comprising ninety-five ¼-acre and four ⅕-acre plots. Each year 30 of these plots are planted to cotton.

When these experiments were started it was recognized that the limited rainfall and its erratic distribution were important factors in crop production. It has developed that cotton root rot also exerted a major influence on the results of these experiments. The losses from root rot were so general throughout the different plots that in 1912 definite observations on its occurrence were made a matter of record. Counts were made of the number of cotton plants killed by root rot on each plot and the loss from the disease was expressed as a percentage of the total number of plants in the plot. Similar observations have been made each year since 1912, so that with the season of 1932 there are available 21-years' records on the extent of the disease in this series of rotations.

During the years these experiments have been under observation it has been apparent that the variation in the losses sustained could be attributed only in part to the treatments the plots received. In certain cases conflicting results have been obtained. Uncontrolled factors have existed in the fields which appear to have had a profound influence on the occurrence of the disease irrespective of rotational or cultural treatment. For instance, it has been observed that the deeper soil near the south end of the series of plots, which has a higher water-holding capacity, has been more favorable for the maintenance of the disease than the more shallow soil with lower water-holding capacity near the north end. The texture of the soil varies considerably and may influence the prevalence of the disease. It has also been observed that in certain instances adjoining portions of plots or rotations with apparently similar soil conditions have shown wide differences in losses sustained even when subjected to similar treatment.

In some cases these differences between plots or rotations appeared the first few years that records were made and have been maintained rather consistently. This indicates that some soil condition which is not yet understood has been an important factor. It is suggested that this persistence of the disease may be due to soil characteristics that enable the organism to maintain itself saprophytically or by means of a resting stage. In arranging the following material, insofar as possible, direct comparisons between the plots receiving different treatments are made where the soil and other conditions are as nearly similar as possible. It is the purpose of this bulletin to present the record of the occurrence of the disease in these rotations during the past 21 years, as affected by the various rotational and cultural treatments.

HISTORICAL REVIEW

The published information on the effect of rotational and cultural practices on root rot of cotton is limited. Pammel (*8*, *9*) in 1888 and 1889 was the first to suggest that root rot might be controlled by proper rotation of crops. He stated (*8*): "I think from a practical point of view a proper method of rotation of crops is the best way to destroy the fungus." In a second publication (*9*) he gave numerous instances of important reduction in root rot by rotation of crops as reported to him by farmers. Shear and Miles (*15*) in 1907 recommended crop rotation combined with deep fall plowing as a means of controlling root rot. Scofield published two reports on the experiments herein discussed, one in 1919 (*13*) and the other in 1921 (*14*). Youngblood (*21*) recommended especially a 3-year rotation of corn with cowpeas planted between the rows, cotton and oats followed by cowpeas sown broadcast. Taubenhaus and Killough (*19*) have pointed out that rotations may fail to reduce the loss from root rot in the presence of susceptible weeds that serve as carriers of the disease. Reynolds and Killough (*12*) reported considerable reduction in root-rot losses over a period of 11 years by rotation. They state:

> It will be observed that the rotated cotton in every case did not have as much root rot as did the cotton grown continuously on the same land. In fact, rotation of crops practically controlled although it did not eradicate the disease.

The effects of clean cultivation and fallow have been reported by several investigators, some obtaining favorable and others unfavorable results. McNamara and Hooton (*6*) have had conflicting results and conclude that a 1-year fallow may or may not give temporary relief from root rot, while a 2-year fallow appeared to give encouraging results but is very expensive to maintain. King and Loomis (*4*) at Sacaton, Ariz., failed to find a reduction of root rot from either 1- or 2-year fallow. The infected areas were the same in size and shape as before the treatment. On the other hand, Taubenhaus and Killough (*19*) recommend a clean fallow combined with the growing of nonsusceptible crops to eradicate the disease completely.

The use of barnyard manure and organic fertilizers has been found by King and Loomis (*2*, *3*) to reduce the loss from root rot. This was in Arizona where irrigation was practiced. In their report of experiments in Texas under dry-land conditions, Taubenhaus and Killough (*19*) stated that it is doubtful if the addition of humus or manure to the soil will greatly influence root-rot control, although it may increase the yield in cotton. Shear and Miles (*16*) advocated deep fall plowing as a means of controlling root rot. Their experiments were carried on for 2 years. They pointed out that the black heavy clay soils of Texas are poorly aerated and, therefore, favorable for the disease. Deep plowing, it was thought, would correct this and destroy the fungus. Taubenhaus and Killough (*19*) carried on experiments from 1917 to 1921 to determine the effect of deep plowing, shallow plowing, and subsoiling. They concluded that "the value of deep plowing as a method of controlling root rot has been exaggerated."

The writers cited appear to agree that the rotation with nonsusceptible crops is a practical and partly successful method of reducing

the losses from the cotton root-rot disease. Opinion is divided regarding the value of other cultural treatments. Widely different results are reported by writers whose observations cover experiments conducted in different localities. In a number of instances the periods covered by the investigations have been of short duration.

SOIL CONDITIONS

The San Antonio Station is located about 6 miles south of the city of San Antonio near the southern edge of what is known as the Black Prairie region or "Black Lands" of Texas and near the northern edge of an area known geologically as the Rio Grande Plain. The soil is the result of weathering of limestone rock, with some modification by alluvial deposits washed down from higher lands to the north. From San Antonio northwest the topography rapidly becomes rough, and the Edwards Plateau region is reached within a few miles of the city. To the south the soil changes to a more sandy type, and the topography is gently rolling. Throughout the region the lime content is very high in the surface soil as well as the subsoil, and in many places there are outcroppings of limestone gravel.

The soil of the station is varied, not only from field to field but also within the limits of a plot. The differences include depth, lime content, and structure, as well as fertility and water-holding capacity. In the northern part of the rotation fields the soil varies in color from light gray to dark brown. In places near the west edge of field B–5 it is less than 2 feet in depth, being underlain by a white limestone formation commonly known as caliche gravel. On the east ends of the same plots on field B–5 the limestone is not reached within 6 feet of the surface. Over most of fields A–4, A–5, B–4, and B–5, however, the surface soil is 2 to 3 feet deep. The subsoil for the most part is a rather heavy clay, chocolate-brown to black in color, with numerous limestone concretions throughout. The four northern fields are nearly level. In general they are less productive, and the water-holding capacity is lower than in fields A–6 and B–6. Starting at the north end of fields A–6 and B–6, the ground slopes definitely to the south and west. The soil is progressively deeper down the slope, and at the south end the black subsoil has a depth of at least 10 feet. The structure of all the soil is such that it is sticky and difficult to cultivate unless moisture conditions are favorable.

CLIMATIC CONDITIONS

The climate at San Antonio is characterized by long summers and short, mild winters. Temperatures during the summer are moderately high, while winter temperatures rarely go below 15° F. The frost-free period averages 260 days. The mean annual rainfall for the period from 1907 to 1932, as recorded at the station, is 26.44 inches. If properly distributed this would insure fair crop production, but droughts of many weeks' duration occur frequently and at any season of the year, although they are more common during the summer months. This condition results in wide fluctuations of crop yields. There is considerable wind movement, particularly during

the summer months, and the total yearly evaporation is high. Light rains and showers during the growing season are of very little benefit to field crops.

In reviewing the data accumulated during the past 21 years at the San Antonio Field Station on the injury to cotton due to the root-rot disease, it appears that the amount of seasonal rainfall has influenced the virulence of the disease. As a rule, the losses have been highest with moderate to high seasonal precipitation. Table 1 shows the monthly precipitation from 1912 to 1932, together with the total for each year and the seasonal rainfall, which includes the months of March to October.

TABLE 1.—*Precipitation (in inches) by months, together with the annual and seasonal totals, San Antonio Field Station, 1912–32*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Seasonal, March to October
1912	0.32	6.26	2.47	1.82	1.64	3.42	0.08	0.25	1.55	2.90	1.76	3.91	26.38	14.13
1913	1.01	1.95	2.74	1.32	2.23	4.27	.27	1.21	9.41	4.06	4.01	4.23	36.71	25.51
1914	.20	1.43	1.13	6.27	6.62	.04	.00	4.28	1.87	3.89	4.20	1.43	31.36	24.10
1915	.48	1.72	1.31	9.05	2.50	.00	1.08	3.48	3.21	1.90	.41	1.50	26.64	22.53
1916	2.30	.00	.53	1.61	3.79	.82	4.72	2.25	4.16	4.48	2.58	.38	27.62	22.36
1917	.81	.46	.13	.74	3.41	.04	3.40	.32	1.73	1.54	.63	.01	13.22	11.31
1918	.04	1.72	.56	3.83	3.36	2.90	1.89	1.33	2.08	3.66	2.32	3.38	27.07	19.61
1919	3.88	1.57	1.74	2.52	2.86	5.79	7.60	2.22	7.06	10.06	.51	1.82	47.63	39.85
1920	4.00	.19	.49	.51	3.78	5.10	1.66	2.39	.03	1.91	1.97	.10	22.13	15.87
1921	1.76	.30	5.41	4.79	.62	4.40	1.40	.02	6.77	.90	1.94	.08	28.39	24.31
1922	.89	.97	4.33	7.12	3.93	4.73	.12	.02	1.07	4.80	.89	.09	28.96	26.12
1923	.38	6.08	2.81	2.69	1.67	2.16	2.16	2.50	3.02	1.38	3.99	4.59	33.43	18.39
1924	.81	3.27	.95	2.20	5.05	6.59	.00	.00	2.14	.25	.17	2.67	24.10	17.18
1925	.20	.06	.30	.21	2.11	.96	.57	1.66	4.00	1.53	1.70	1.64	14.94	11.34
1926	2.83	.10	4.68	6.65	1.65	3.92	1.39	.38	.39	2.54	1.63	2.14	28.30	21.60
1927	.67	1.84	2.17	1.75	1.72	7.71	.36	.05	1.83	2.10	[1] T	2.30	22.50	17.69
1928	.83	2.30	2.05	2.03	5.35	4.65	.58	2.66	4.97	1.49	1.89	2.41	31.21	23.78
1929	1.35	.15	2.64	2.56	8.23	2.34	3.12	.05	2.38	1.87	2.95	1.81	29.45	23.19
1930	1.35	.76	2.02	2.03	1.11	3.48	2.78	.07	1.64	4.17	3.58	.94	23.93	17.30
1931	5.67	2.32	2.93	2.25	1.82	3.82	4.35	.43	.13	1.35	.88	3.43	29.38	17.08
1932	3.70	1.87	1.30	1.41	2.68	2.03	2.99	3.86	3.57	.76	.13	1.23	25.53	18.60
Mean	1.59	1.68	2.03	3.12	3.15	3.29	1.93	1.40	3.00	2.74	1.82	1.91	27.57	20.56

[1] T = trace.

DESCRIPTION OF EXPERIMENTS

The rotation and tillage experiments here described occupy two series of fields, designated A and B. Each series is divided into 5-acre fields, which are in turn divided into 18 quarter-acre plots, except field A–4 in which there are 15 quarter-acre plots and 4 fifth-acre plots. Only the south 8 plots on field B–4 are utilized in the rotations. Each quarter-acre plot is 41.25 feet wide by 264 feet long. An alleyway of 4.75 feet is provided between plots, making the distance across plots, between center lines of alleys, 46 feet. When occupied by row crops there are 10 rows spaced 4.1 feet apart and 264 feet long on each plot. The fifth-acre plots on field A–4 have low borders of earth around each of them to prevent run-off of precipitation, and they are 138 feet wide by 66 feet long. They accommodate 32 rows of cotton spaced 4.1 feet apart.

Four plots are continuously cropped to cotton. There are 17 rotations in which cotton occurs every second year, 4 in which it occurs every third year, and 2 in which it occurs every fourth year. There are 30 plots of cotton available for study each year, which are grown

under a definite schedule of cultural treatments, season after season. There are as many plots for each rotation as there are major crops, thus allowing each crop in each rotation to be grown every year.

In making observations on the loss of cotton plants from root rot, the following method was adopted: The cotton was thinned by hand when 6 to 8 inches tall, leaving single plants as nearly as possible 1 foot apart. A count was made of all plants on each plot soon after thinning. At the end of the season a count was made of the dead plants on each plot. The loss has been expressed as a percentage of the total number of plants at the beginning of the season. Starting in 1916, diagrams were made at the close of each season showing the locations of dead plants on all cotton plots. These diagrams have made possible a study of the recurrence of the disease with respect to both location and spread. During 1919, and each season thereafter, biweekly counts of dead plants were made from the time the first plants started dying until the latter part of October. This afforded an opportunity to study the rate of spread of the disease during the growing seasons.

The crop sequences and cultural treatments of rotations which included cotton are listed below. The system of designating plots and rotations is as follows: The first letter refers to the series, and the first numeral refers to the field; the next character, if a numeral, refers to the plot, while if a letter it refers to the rotation.

Plots cropped continuously to cotton

A–4–19. Cotton, field peas (plowed under in spring).
A–6–3. Cotton (plowed in November).
B–5–3. Cotton (plowed in November).
B–5–4. Cotton, manure (plowed in November).

Cotton on the same land every second year

A–4–A. Cotton (plowed in November); fallow (approximately 17 months).
A–4–D. Cotton (plowed in November); corn (plowed in July; plots bordered).
A–5–C. Cotton (plowed in November); milo (plowed in July); cotton (plowed in fall); oats (plowed in June).
A–5–D. Cotton (plowed in November); milo, manure (plowed in July); cotton (plowed in fall); oats, cowpeas (plowed under in fall).
A–5–E. Cotton (plowed in November); milo, manure (plowed and subsoiled in July); cotton (plowed in fall); oats, cowpeas (plowed under and subsoiled in fall).
B–5–A. Cotton (plowed in November); sorgo, 4.1-foot rows (plowed in November).
B–5–B. Cotton (plowed in November); sorgo, 8-inch drills (plowed in November).
B–5–E. Cotton (plowed in November); milo (plowed in July).
B–6–A. Cotton (plowed in November); corn (plowed in July).
B–6–B. Cotton (plowed and subsoiled in November); corn (plowed and subsoiled in July).
B–6–C. Cotton (plowed in November); corn, manure (plowed in July).
B–6–D. Cotton (plowed in November); corn, manure; field peas (plowed under in spring).
B–6–E. Cotton (plowed and subsoiled in November); corn, manure; field peas (plowed under in spring).
B–6–F. Cotton (plowed in November); corn (disked in July).
B–6–G. Cotton (plowed in February); corn (plowed in February).
B–6–H. Cotton (plowed and subsoiled in February); corn (plowed and subsoiled in February).
B–6–I. Cotton (plowed in November); corn, rye (plowed under in February).

Cotton on the same land every third year

A–5–A. Cotton (plowed in November); milo (plowed in July); oats (plowed in June).

A–5–B. Cotton, manure (plowed in November); milo (plowed in July); oats (plowed in June).

B–4–A. Cotton (plowed in November); milo (plowed in July); Sudan grass (plowed in November).

B–4–B. Cotton (plowed in November); milo (plowed in July); oats, field peas (plowed under in spring).

Cotton on the same land every fourth year

A–4–F. Cotton (plowed in fall); oats (plowed in June); milo, field peas (plowed under in spring); sorgo, 8-inch drills (plowed in November).

A–4–G. Cotton (plowed in fall); oats (plowed in June); milo, field peas for hay (plowed in spring); sorgo, 8-inch drills (plowed in November).

Figure 1 shows the relative position of the various rotations in series A and B.

CULTURAL PRACTICES

The cultural practices used were in accordance with what is considered good farming procedure for the locality. The plots were plowed to a depth of approximately 8 inches with a reversible disk plow, throwing the earth all one way. Where subsoiling was practiced the subsoil plow was run in the furrow behind the disk plow, loosening the soil to an additional depth of 6 to 8 inches. When manure occurred in the rotation it was applied at the rate of 16 tons per acre, just ahead of plowing. During the interval between plowing and planting the subsequent crop the plots were cultivated with a disk harrow or orchard cultivator as frequently as necessary to control weed growth.

Cotton was planted as soon after April 1 as weather and soil-moisture conditions were favorable. The land was disked and drag-harrowed to make a uniformly level seed bed. The crop was cultivated throughout the season as often as was necessary to keep down weed growth.

PRESENTATION OF DATA

In recording the behavior of the cotton root-rot disease in the rotation

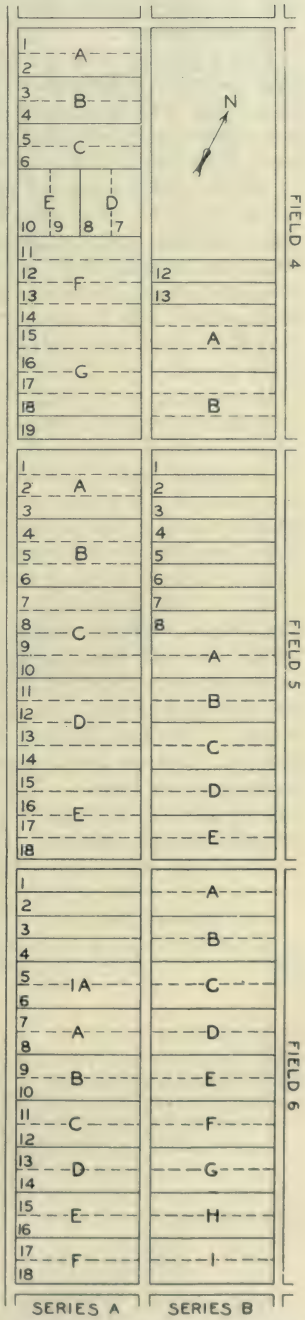

FIGURE 1.—Location of rotation experiments, San Antonio Field Station.

and tillage fields two methods were employed—statistical and diagrammatical.

For a proper interpretation of yield data it was recognized in 1912 that definite information as to the extent of loss of cotton plants on each plot was necessary in order to compensate, if practicable, for variations between those on which a large percentage of the plants were killed and those on which a few or no plants died. On August 13 of that year a record was made of the total number of dead plants on each plot. For the 1913 and 1914 seasons similar counts were made during August and early September. In all subsequent years the final counts have been made after September 28. Inasmuch as the most rapid rate of spread of the disease usually occurs during September, the losses recorded for the first 3 years are minimized and therefore not fairly comparable with the results recorded for later years.

Beginning with 1919, more extensive records of the spread of the disease during the season were made. As soon as the first cotton plants were found to be dying of root rot, usually the first week of June and biweekly thereafter until the end of the season, a close inspection of all plots was made and the number of wilted and dead plants on each plot was noted. For comparative purposes these data have been reduced to percentages of total stand, and the results at the time of the last count for each season are presented in table 2. The rotations are grouped according to the number of years between cotton crops. At the right of the table are shown plot and rotation means for all years, standard error [3] of the mean of each rotation, mean of each rotation for the period 1915–22, mean of each rotation for the period 1923–32, and the increase (+) or decrease (−) of the mean of the last 8 years of record as compared with the first 8-year period. Losses for the years 1925 and 1928 are not included in computing mean losses. Extremely dry weather in 1925 prevented the emergence of any plants on some plots and seriously reduced the growth on all others. In 1928 the crop was totally destroyed on most of the plots by a hailstorm which occurred on June 10.

[3] The standard error of the mean has been calculated from the formula $\sqrt{\frac{\Sigma d^2}{N(N-1)}}$ in which N represents the number of years and d^2 indicates the summation of the squared deviations from the mean.

TABLE 2.—*Losses of cotton plants from root rot in the rotation and tillage experiments at the San Antonio (Tex.) Field Station, 1912–32*

[The losses are given as percentage of total stand]

Rotation	Plot	Year																			Plot mean	Rotation mean			
		1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1929	1930	1931	1932		1912–32	1915–22	1923–32	Increase, second over first period
Cotton continuously:																										
A-4-19	A-4-19		2.7	4.2	11.8	42.0	10.1	25.6	32.3	5.6	85.1	1.2	76.9	8.6	3.0	10.7	40.9	16.1	86.1	39.0	33.3	29.6	29.6±6.6	26.7	39.0	12.3
A-6-3	A-6-3	0.7	.8	.5	.7	7.4	15.1	9.2	19.5	24.2	81.3	2.6	75.4	44.0	1.9	17.9	82.5	32.8	86.2	72.3	36.0	32.1	32.1±7.3	20.0	55.9	35.9
B-5-3	B-5-3	.9	3.8	17.6	49.7	96.2	43.7	30.4	95.5	39.7	96.6	2.6	88.5	37.1	.2	3.0	85.4	3.8	96.8	17.2	70.9	46.3	46.3±8.6	56.8	50.3	−6.5
B-5-4	B-5-4	.2	.8	2.5	10.5	60.5	36.8	41.9	74.3	2.3	94.6	.6	70.5	8.5	1.9	4.1	61.6	17.3	75.8	24.0	49.4	33.5	33.5±7.2	40.2	38.9	−1.3
Cotton every second year:																										
A-4-A	A-4-1		.1		1.3		4.7		48.6		75.1		67.7				36.8	96.5		98.6		47.7				
	A-4-2	.0		.0		3.2		27.2		44.2		7.8		73.5		37.4			83.5		56.2	33.3	40.1±8.0	26.5	68.8	42.3
A-4-D	A-4-7		1.5		14.0		29.0		27.5		18.1		8.2				16.8	31.8		74.5		24.6				
	A-4-8	.0		.0		12.5		19.4		24.0		1.5		31.2		57.3			20.5		10.1	17.7	20.9±4.4	18.3	31.3	13.0
B-5-1	B-5-9		.0		.0		.0		3.3		5.3		15.2				.1	1.3		52.4		8.6				
	B-5-10	.0		.1		2.2		.4		.0		7.0		6.9		2.7			8.1		1.5	2.9	5.6±2.8	2.3	11.0	8.7
B-5-B	B-5-11		.0		.2		.0		8.6		37.3		56.4				.7	10.7		82.8		21.9				
	B-5-12	.0		.1		5.6		11.0		34.1		17.0		25.7		14.2			18.1		8.1	13.4	17.4±5.1	14.2	27.1	12.9
B-5-E	B-5-17		2.2		1.3		4.1		15.1		29.5		35.6		.6		15.6	37.1		74.9		23.9				
	B-5-18	.6		.3		3.0		8.1		9.1		35.0		27.2		29.9			24.2		15.1	15.3	19.4±4.3	13.2	32.4	19.2
B-6-A	B-6-1	.7		.0		2.0		4.9		5.1		14.8		16.2		38.1			36.4		55.0	17.3				
	B-6-2		.0		.0		.8		.2		10.5		14.9		1.8		2.7	8.8		31.1		7.9	12.7±3.7	4.8	25.4	20.6
B-6-B	B-6-3	.0		.0		1.3		8.0		1.5		5.5		13.3		16.0			25.7		37.3	10.9				
	B-6-4		.1		.0		.8		6.8		5.7		45.1		1.0		.2	4.4		20.7		9.4	10.1±3.1	3.7	20.3	16.6
B-6-C	B-6-5	.0		.4		.3		1.6		.0		10.2		13.1		11.1			4.0		1.0	4.2				
	B-6-6		.6		.0		1.9		3.9		6.5		16.3		11.8		1.2	5.0		26.9		6.7	5.5±1.6	3.1	9.8	6.7
B-6-D	B-6-7	.0		.0		.0		8.3		9.4		12.8		30.4		41.6			17.4		5.3	12.5				
	B-6-8		.0		.2		1.0		5.4		9.4		28.4		3.3		5.4	22.2		30.5		11.4	12.0±2.9	5.8	22.7	16.9
B-6-E	B-6-9	.0		.5		4.5		13.8		18.4		21.4		50.6		55.2			41.1		7.2	21.3				
	B-6-10		.2		2.3		3.9		12.6		13.6		68.5		6.9		7.0	31.4		53.2		21.4	21.3±5.0	11.3	39.3	28.0
B-6-F	B-6-11	1.1		3.5		51.8		6.5		15.4		12.5		40.9		26.9			19.9		27.9	20.6				
	B-6-12		.7		3.9		10.6		21.3		33.8		88.4		1.5		8.1	38.6		79.2		31.6	25.8±5.8	19.5	41.2	21.7
B-6-G	B-6-13	2.5		12.8		100.0		8.5		37.7		21.0		66.0		81.5			48.9		67.8	44.7				
	B-6-14		13.2		45.7		23.2		51.4		77.6		90.8		1.2		17.4	82.5		83.9		54.0	49.1±7.3	45.6	67.4	21.8
B-6-H	B-6-15	2.0		4.8		81.7		5.4		20.2		10.1		32.8		45.5			52.1		46.0	30.1				
	B-6-16		1.6		14.2		36.6		63.6		60.3		66.8		1.9		6.7	34.5		75.1		39.9	34.7±6.1	36.5	44.9	8.4
B-6-I	B-6-17	.3		.6		15.5		31.4		21.1		12.5		35.4		23.6			39.9		72.5	25.3				
	B-6-18		.6		.4		.5		40.7		59.4		70.6		1.0		4.0	34.5		83.0		32.5	28.8±6.2	22.7	45.4	22.7

TABLE 2.—*Losses of cotton plants from root rot in the rotation and tillage experiments at the San Antonio (Tex.) Field Station, 1912–32*—Con.

[The losses are given as percentage of total stand]

Rotation	Plot	Year																			Plot mean	Rotation mean			
		1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1929	1930	1931	1932		1912–32	1915–22	1923–32	Increase, second over first period
Cotton every second year.—Con.																										
A–5–C	A–5–7	.3		.2		13.0		9.8		6.8		17.7		29.1		23.8			21.3		20.0	14.2				
	A–5–8		2.1		11.6		17.2		39.0		41.9		35.6		8.1		5.5	15.0		67.2		26.1				
	A–5–9	.0		.1		18.0		30.0		22.7		16.0		30.9		23.8			22.4		10.4	17.4				
	A–5–10		.3		4.3		5.6		24.8		60.0		69.6		.8		35.1	70.9		84.6		39.5	23.9±3.5	21.2	35.3	14.1
A–5–D	A–5–11	.2		.2		22.6		21.2		14.4		4.6		13.5		19.7			41.7		6.7	14.5				
	A–5–12		1.1		14.3		15.0		59.0		83.6		26.0		.0		.0	2.4		38.2		26.6				
	A–5–13	.2		.0		43.2		46.9		6.7		5.6		11.6		10.7			5.0		3.3	13.3				
	A–5–14		1.2		6.7		20.8		35.4		15.7		14.8		.2		.0	5.1		15.6		12.8	16.7±3.0	26.6	13.4	−13.2
A–5–E	A–5–15	.3		1.4		14.8		5.2		.1		.1		6.0		5.8			6.9		7.7	4.8				
	A–5–16		.1		.0		.2		1.5		8.6		5.8		.1		.1	.4		1.3		2.0				
	A–5–17	.0		.0		3.7		3.4		.0		.9		.8		1.4		.7			1.8	1.3				
	A–5–18		.0		.2		1.6		.9		1.7		1.4		.0		.0	.5		2.3		1.0	2.3± .5	2.7	2.7	.0
Cotton every third year:																										
A–5–A	A–5–1		.0			2.0			4.7			.3			3.6					5.7		2.5				
	A–5–2	.0			.0			.0			4.2			.0			8.0		17.2			4.2				
	A–5–3			2.0			1.9			.0			33.9			4.1		30.8			12.8	12.2	6.7±2.3	1.6	14.1	12.5
A–5–B	A–5–4		.0			.0			4.2			1.3			2.8					2.3		1.6				
	A–5–5	.0			.0			2.5			7.5			3.4			1.6		12.5			3.9				
	A–5–6			.1			1.6			5.5			48.1			26.6		26.0			10.3	16.9	8.1±2.9	2.8	16.4	13.6
B–4–A	B–4–14			.3			.0			.0			26.9			5.3		14.6			15.2	8.9				
	B–4–15		.0			.0			1.8			.5								.9		.6				
	B–4–16				.9			.7			7.6			.0			.3		1.0			1.8	4.2±1.8	1.4	8.0	6.6
B–4–B	B–4–17			1.1			2.6			6.4			4.1			.0		1.7			5.8	3.1				
	B–4–18		.2			9.3			26.5			.0			.0					1.8		7.6				
	B–4–19				1.4			1.5			11.9			3.9			.0		1.0			3.3	4.4±1.5	7.4	2.3	−5.1
Cotton every fourth year:																										
A–4–F	A–4–11					1.6				.0				.0							3.4	1.3				
	A–4–12				.0				.7				1.4				.7			1.7		.9				
	A–4–13			.0				.1				.2				.5		.4				.2				
	A–4–14		.4				.1				8.0							2.0				2.6	1.2±.46	1.34	1.26	−.08
A–4–G	A–4–15					26.0				20.2				17.5							8.5	18.1				
	A–4–16				18.5				51.9				6.4				2.6			9.8		17.8				
	A–4–17			1.5				.5				.1				1.6			.5			.8				
	A–4–18		3.8				2.9				6.6							1.5				3.7	10.0±3.1	15.8	6.1	−9.7
Annual mean		.4	1.3	1.8	7.1	21.5	9.7	12.8	26.0	13.2	35.2	8.1	41.9	22.0	2.3	21.3	14.9	22.7	30.9	41.7	23.6		17.4			

ROTATIONAL TREATMENTS COMPARED

In considering the data record over a period of 21 years for these experiments, which involve various crop sequences and cultural treatments, it is apparent that there are numerous inconsistencies. Wide variations in the prevalence of the disease occurred not only between similar rotations but also between individual plots within the same rotation. Also, the relative ranking of the rotations fluctuated between wide limits from year to year. It is apparent that other factors exerted a major influence on the occurrence of the disease and rendered the interpretation of the recorded data difficult from the point of view of determining the comparative merits of the different treatments.

If the crop sequences and the cultural treatments applied had been predominant in influencing the occurrence of the disease, conclusions drawn from a comparison of the data from the standpoint of mean infection over the 21-year period should coincide with those drawn from a comparison of the relative increase or decrease in severity of infection during the 8-year periods. Owing to the major influence of the uncontrolled variables, however, the two methods of comparison often afford widely different indications.

Another inconsistency noted in these data emphasizes the importance of the uncontrolled factors, for in many instances the difference in mean losses between plots within a rotation is greater than between mean losses of different rotations. The seasonal rainfall together with its distribution and other climatic phenomena might be a primary cause for these wide intrarotation variations. This can hardly be the case, however, as it was found that in some 2-year rotations those plots which were in cotton in the odd years were the more heavily infested, while in others the even-year plots had the higher losses. This point was very forcibly illustrated in the 4-year rotation A–5–D, in which cotton recurred every other year and the four plots were each subjected to identical treatments during the cycle. Plots 11 and 13 were cropped to cotton in the even years and had 21-year mean losses of 14.5 and 13.3 percent, respectively. Plots 12 and 14 were in cotton in the odd years and had mean losses of 26.6 and 12.8 percent, respectively. Considering the pair of plots, 11 and 12, the greater loss occurred during the odd years, while in the other pair, 13 and 14, the loss was greater during even years. These percentage figures are supplemented by the infection maps appearing elsewhere in this bulletin, which portray very definitely the actual behavior of the fungus under field conditions.

Some rather definite trends have seemed apparent in certain instances when considered for only 3 or 4 years, but these trends have been obscured or greatly minimized when the data for the entire 21-year period are studied. Thus it appears that under the conditions existing where these experiments have been conducted there is danger of overestimating the effectiveness of such treatments as are available for consideration in the series of rotations herein listed.

COTTON GROWN CONTINUOUSLY

A comparison of the four plots which were cropped annually to cotton, on the basis of their mean losses over the 21-year period, indi-

cates that barnyard manure applied at the rate of 16 tons per acre (plot B–5–4) was effective in holding down the losses as compared with the adjoining plot (B–5–3) which received no special treatment. Their 21-year mean losses in percentage of stand were 33.5 and 46.3, respectively. In comparing these same two plots on the basis of their mean losses for the first and second 8-year periods, respectively, they each showed a slight decrease in mean loss, the difference being in favor of the plot which received no manure.

In the same manner the 21-year mean loss on plot A–4–19, where a crop of field peas for green manure was grown each winter, was 29.6 percent as compared with a mean loss of 46.3 percent on the nearby untreated plot, B–5–3. However, the untreated plot showed a decrease in loss during the last 8-year period, while the plot which had a green-manure crop plowed under each year showed a very appreciable increase in loss.

By similar comparisons the disease appeared slightly more severe where barnyard manure was applied annually than where field peas were grown for green manure each winter, on the basis of their 21-year mean losses, while the opposite conclusion is indicated on the basis of their relative losses during the two 8-year periods.

A comparison of the 8-year period losses of the two plots, A–6–3 and B–5–3, which received identical cultural treatments and no amendatory treatment, shows that the losses on the first increased from 20.0 percent to 55.9 percent, while on the latter they decreased from 56.8 to 50.3 percent.

COTTON GROWN EVERY SECOND YEAR

There were 17 rotations in which cotton was planted on the same land every second year. In one, A–4–A, the land was held in clean fallow from the time the cotton stalks were plowed under in November until the crop was planted the second spring following—a period of about 17 months. Thirteen were 2-year rotations with corn or sorghums involving various cultural practices. Three were 4-year rotations with similar crop sequences—cotton, milo, cotton, oats—and varying only as to cultural practices involved. Ranking these rotations from 1 to 17 in the order of mean severity of infection and again in the order of those showing greatest decrease in infection to those showing the greatest increase, inconsistency is apparent.

In these 17 rotations 20 plots were planted to cotton each year. One alternated with clean fallow, 2 alternated with sorgo, 3 followed oats, 4 followed milo, and 10 alternated with corn. With only one exception the rotation in which cotton alternated with clean fallow had the highest mean loss of the 2-year rotations. In fact, the mean loss in this rotation was higher than for 3 of the 4 continuously cropped plots. There was also an appreciable increase in the amount of infection in this rotation in the last 8-year period as compared with the preceding 8-year period.

The 21-year mean loss in the rotation in which cotton alternated with sorgo planted in 4.1-foot rows (B–5–A) was only 5.6 percent; while the mean loss in B–5–B, in which the sorgo was in 8-inch drills, was 17.4 percent, the latter appearing to be three times worse than the former. However, the loss increased approximately 2.5 times faster

in the rotation having the sorgo in 4.1-foot rows than in the one having close-drilled sorgo when compared on the basis of the two 8-year periods. It seems improbable that merely the manner of planting the intervening crop caused the variation between these rotations (fig. 2).

The three plots in which cotton followed oats each year were in 4-year rotations in which cotton recurred every other year, first after oats, next after milo, and then following oats again. Only one of these (A–5–C) was an untreated rotation, the other two involving barnyard and green manures and subsoiling. In the untreated rotation the mean loss following oats was 23.8 percent. Comparing the 8-year means, there was an increase in losses from 19.6 percent to 36.3 percent.

Four plots of cotton followed milo each year—three in the 4-year rotations as described above and one in a 2-year rotation (B–5–E).

FIGURE 2.—Cotton as it appeared October 9, 1931, in a 2-year rotation with close-drilled sorgo (B–5–B). More than 80 percent of the plants on this plot were killed by root rot.

The 21-year mean loss where cotton followed milo in the 4-year rotation was 24.0 percent and in the 2-year rotation 19.4 percent. A comparison of their respective 8-year means, however, shows that the losses in the 4-year rotation increased from 22.8 to 34.3 percent, while the losses in the 2-year rotation increased from 13.2 percent during the first period to 32.4 percent during the second period.

Although there were ten 2-year rotations in which cotton and corn alternated, all except two were complicated by various cultural or manurial treatments. One of the excepted rotations was bordered to prevent run-off of rainfall, but for purposes of root-rot study it may be compared with other similar rotations. These two rotations, A–4–D and B–6–A, had 21-year mean losses of 20.9 and 12.7 percent, respectively. In the first the odd-year plot mean loss was 139 percent of that of the even-year plot mean loss, while in the second one the odd-year plot loss was only 45.7 percent of that of the even-year plot.

COTTON GROWN EVERY THIRD YEAR

The crop sequences in the four 3-year rotations were very similar in all and identical in three. The 21-year mean loss was low in each. There was a wide variation in mean loss between the individual plots of each rotation. A study of the yearly losses in these rotations reveals that in A–5–A, A–5–B, and B–4–A the heaviest losses occurred the same years in each. This correlation does not hold when B–4–B is included, however, as almost without exception its heaviest losses occurred in the years when the first three sustained relatively small loss. When the two 8-year periods are compared it is found that each of the first three rotations shows a large increase of losses, while B–4–B shows an appreciable decrease of losses.

FIGURE 3.—Cotton on the continuously cropped plot A–4–19 (left) compared with that on plot A–4–18, which is in a 4-year rotation with oats, milo, and close-drilled sorgo. October 5, 1921.

COTTON GROWN EVERY FOURTH YEAR

There were two rotations in which cotton recurred on the same land each fourth year—A–4–F and A–4–G. The only difference between them was that in the F plot the winter crop of field peas was plowed under for green manure, while in the G plot the growth of peas was harvested for hay. Inasmuch as there was seldom sufficient growth to permit harvesting for hay, the two rotations were for all practical considerations identical as to treatment. Six of the eight plots involved in these two rotations had low losses consistently throughout the duration of the experiment, while plots 15 and 16 in rotation A–4–G had rather consistently high losses. Both rotations showed a decrease in losses during the last 8-year period, especially A–4–G. The effectiveness of a 4-year rotation in checking the spread of root rot is shown in figure 3, when spread from the heavily infected, continuously cropped plot had not killed any plants across the narrow alleyway in plot A–4–18 at the end of the season.

EFFECT OF CULTURAL TREATMENTS

BARNYARD MANURE

The effect of applications of barnyard manure on the occurrence of cotton root rot may be studied in one pair of continuously cropped plots, in one pair of 2-year rotations, and in one pair of 3-year rotations. Barnyard manure was applied in several other rotations, but the inclusion of other treatments makes direct comparisons with them impracticable.

Adjacent plots, B–5–3 and B–5–4, were cropped continuously to cotton. The land was plowed each year in November. Plot 3 received no special treatment, while manure was spread broadcast at the rate of approximately 16 tons per acre on B–5–4 just ahead of plowing. Although records of infection were not made until the fourth year of these experiments, the loss on the untreated plot was somewhat greater than on the manured one from the beginning. Their mean losses for the period covered by the records were 46.3 and 33.5 percent, respectively. Both plots showed a small reduction in losses during the last 8 years as compared with the first period, the greater decrease being in the unmanured plot. In the pair of 2-year rotations, B–6–C, which received manure plowed under in July ahead of the cotton crop, had a lower mean loss than the untreated one, B–6–A. The difference in mean losses between the two plots of the latter rotation was greater, however, than between the means of the two rotations. Losses were greater in both cases for the last 8-year period than for the preceding 8 years, but they increased at a faster rate in the rotation not manured. A–5–A and A–5–B are similar 3-year rotations of cotton, milo, and oats except that in the latter barnyard manure was applied after the cotton and plowed under ahead of the milo crop. The mean loss for the unmanured rotation was slightly less than for the manured one, but here again the difference between mean losses for the plots of each rotation were much greater than between the rotation means. In both cases the increase of losses for the second period over the first period was large.

In experiments under irrigation at Sacaton, Ariz., King and Loomis (*2*) observed a marked retarding of the disease during the early part of the season and a marked reduction in total loss for the season from applications of manure and rotted alfalfa. After several years' treatment very few plants were killed in the treated plots. In most years the activity of the disease was so delayed that a good crop of cotton was produced on plants which died later. This retarding effect could not be observed in either the continuously cropped plot or in rotations at San Antonio. In this connection it is believed important to consider that at Sacaton the manure was placed in trenches directly beneath the rows of cotton, while at San Antonio the manure was broadcast and plowed under. Taubenhaus and Killough (*19*), after 5 years of experimenting under dry-land conditions in Texas, concluded that it is doubtful if the addition of humus or manure to the soil will greatly influence the occurrence of root rot.

Figure 4 shows the results of a study to ascertain if the decreased loss on the continuously cropped plot which received manure was more evident at one part of the season than another. The accumulated loss in percentage of total plants is plotted for each biweekly period from June 1 to the end of the season. This is for the 13-year period 1919–32, exclusive of 1928. It will be noted that the spread was consistent throughout the season and that during the first 2 months it was at a somewhat faster rate in the unmanured plot. After mid-August the rate of increase was practically the same in both plots. Manure used in these experiments invariably contained a large amount of weed seed, especially seed of pigweeds, or "careless weeds" (*Amaranthus* spp.). When the early growing season was too wet to permit proper cultivation, these weeds so completely retarded the development of the cotton plants as to set them back several weeks as compared with plants on unmanured plots. This condition may have been a factor in influencing the spread of the root-rot disease in this manured plot.

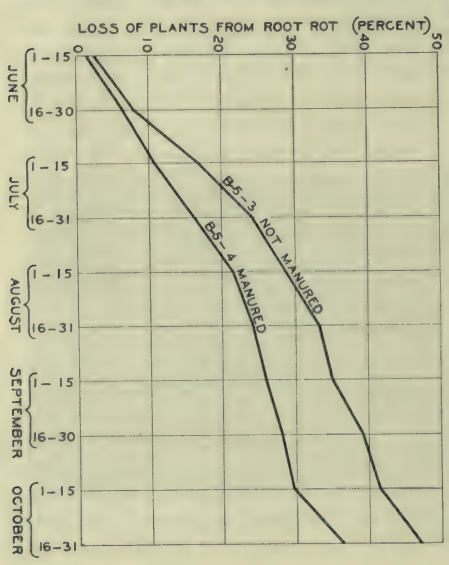

FIGURE 4.—Average seasonal spread of root rot in continuously cropped plots B–5–3 and B–5–4, 1919–32, San Antonio Field Station.

SUBSOILING

The possibility of reducing the loss from root rot by deep tillage was first suggested by Shear and Miles (*15*). In field experiments carried on for only 2 years near Petty, Tex., they obtained some very striking reductions in root-rot loss by deep fall plowing and as a result advocated this practice as a means of controlling the disease. Taubenhaus and Killough (*19*) carried on an experiment for 5 years, testing deep plowing and subsoiling, fall plowing, and spring plowing. They failed to obtain favorable results from any of these methods of treatment. Their observations on subsoiling were confined to one plot.

In these experiments there were two 2-year rotations in which preparation for cotton included subsoiling. Each of these may be compared with an adjacent similar rotation which was not subsoiled. The two 4-year rotations, A–5–D and A–5–E, in which cotton occurred every other year, were likewise similar except that subsoiling was done ahead of each cotton crop in E but not in D. In these 4-year rotations and in one pair of 2-year rotations, B–6–A and B–6–B, the land was plowed and subsoiled in the summer following harvesting of the cereal crop. These operations in the other 2-year rotations, B–6–G and B–6–H, were performed in February. A study of the data recorded for this spring-plowed and subsoiled rotation

shows that the losses, as expressed by their 21-year means, were about one third less as a result of subsoiling. Both these rotations had greater losses during the last 8-year period than during the first, but the increase in the one subsoiled was decidedly less than in the one not so treated.

A similar study of the data for the two pairs of rotations which were plowed and subsoiled in the summer, approximately 9 months before the cotton crop was planted, shows the 21-year mean loss of the subsoiled 2-year rotation to be slightly less than the mean for the one not so treated. However, the mean loss for plot B–6–2 of the nonsubsoiled rotation was less than the mean for either of the plots of the subsoiled one. Both rotations showed a heavy increase in losses, the subsoiled one showing slightly less increase than the one that was plowed only. The mean losses in the plowed and in the subsoiled 4-year rotations, A–5–D and A–5–E, were 16.7 and 2.3 percent, respectively, indicating a marked reduction effected by subsoiling. However, when the mean losses for the individual plots of these rotations are examined, it is found that they are progressively less from A–5–12 through A–5–18, indicating that some undetermined factor may have influenced the losses more than has the operation of subsoiling. The losses in the rotation which was plowed only, A–5–D, were appreciably lower during the last 8-year period as compared with the first period, while in the one subsoiled there was neither a reduction nor an increase of mean loss.

The recorded data indicate a slight benefit from subsoiling in the spring just ahead of cotton in the one pair of rotations in which this practice is comparable with spring plowing. In two sets of rotations where the operations of plowing and subsoiling were performed in the summer approximately 9 months ahead of the cotton crop, the data showed negative benefits as the result of subsoiling.

DISKING COMPARED WITH PLOWING

An opportunity is afforded in these experiments to observe the effects of disking the land in preparation for the cotton crop as compared with the practice of plowing. In both 2-year rotations B–6–A and B–6–F, which include cotton and corn, the land was plowed in November following the cotton crop. The following spring corn was planted on each and the cornland plowed in July in the case of B–6–A and only disked in July in the instance of B–6–F. Both rotations were again disk-harrowed and spike-tooth harrowed to prepare a seed bed just before planting the cotton. For the 21-year period of recorded data the mean root-rot losses of these rotations were 12.7 and 25.8 percent, respectively, while their comparative increases of mean loss for the two 8-year periods were from 4.8 to 25.4 percent and from 19.5 to 41.2 percent, respectively. The uncontrolled factors evidently predominated in these rotations, and it is doubtful if much confidence should be placed in results shown by either method of comparison.

GREEN MANURE

Cotton was grown each year on nine plots following a green-manure crop. On the continuously cropped plot, A–4–19, and in

rotations A–4–F and A–4–G, B–4–B, B–6–D, and B–6–E, Canadian field peas were planted in the fall and plowed under in the spring. In rotations A–5–D and A–5–E cowpeas were planted as soon as possible after harvesting the oat crop and were plowed under in the fall. In rotation B–6–I the cornstalks were chopped with a stalk cutter and rye seeded in the fall. The growth, if any, was plowed under in the spring. Under the erratic rainfall conditions existing at San Antonio the growth of green manure from any of these crops usually was insignificant. Under optimum conditions the green weight rarely exceeded 3 to 4 tons per acre.

In comparing two continuous cotton plots, A–4–19 and B–5–3, which were situated close together, the mean losses for the period of record were 29.6 and 46.3 percent, respectively, apparently a considerable difference in favor of A–4–19, in which green manure was incorporated. When the trend of the disease is studied on the two plots, as indicated by its relative severity during the two 8-year periods, an opposite conclusion is reached. The losses increased from 26.7 to 39.0 percent in the green-manure plot, while they decreased slightly in the untreated one. The 2-year adjoining rotations, B–6–C and B–6–D, yielded results indicating the undesirability of incorporating a green-manure crop ahead of the cotton, whether compared on the basis of their mean losses for the 21-year period or on the basis of relative increase of loss.

A green-manure crop ahead of the cotton in a 3-year rotation of cotton-milo-oats-cotton was effective in limiting the occurrence of root rot if the results indicated in a comparison of rotations A–5–A (untreated) and B–4–B are accepted. The 21-year mean losses were small in both rotations, but the increase during the last 8-year period as compared with the first 8-year period was from 1.6 to 14.1 percent in the untreated rotation, while in the green-manure rotation the losses decreased from 7.4 to 2.3 percent.

FALLOW

The effect of fallow upon the spread and loss from root rot has been studied by several investigators. Taubenhaus and Killough (*19*) recommended a method for controlling the disease, consisting of fallow and rotation with nonsusceptible crops. In recommending a 1 year fallow they point out that the loss in crops during that year will be more than compensated for by the increase in cotton the following year. From experiments at Greenville, Tex., McNamara and Hooton (*6*) report that "a 1-year fallow may temporarily reduce root-rot infection, but it gives little permanent relief and not enough to recommend its use alone." A 2-year fallow they found fairly successful in several cases. One plot which showed more than 90-percent infection for the 3-year period 1919–21, inclusive, showed no infection when returned to cotton after a 2-year fallow. Even after four consecutive seasons in cotton the disease did not reappear. Under irrigation, King and Loomis (*3*) found that a 2-year fallow failed to control the disease and that the infected area had extended itself even in the absence of host plants.

While the effect of fallow may be observed in only one rotation in these experiments, it has been maintained over so long a time that it furnishes considerable evidence upon the subject. Rotation A–4–A

consists of two plots alternately cropped to cotton. The plot not cropped has been fallowed from time of plowing out the cotton crop until time of planting the second season, or for a period of about 17 months. This rotation may be compared with the continuously cropped plots A–6–3 and B–5–3, and with a simple 2-year rotation A–4–D, consisting of corn and cotton.

During the first 5 years of the experiment there was very little loss from root rot in rotation A–4–A. However, the disease spread until the entire area was infected. The mean loss for the rotation was 40.1 percent, and the mean loss during the last 8-year period was more than double the mean loss of the first period. The average mean loss of the two continuously cropped plots mentioned was 39.2 percent, while that of the 2-year rotation A–4–D was 20.9 percent. Extreme drought prevented a stand of cotton in 1925. Although plot A–4–1 was therefore held in clean fallow from November 1923 until April 1927, a period of 3 years and 4 months, 36.8 percent of the plants died during the season of 1927. The infection was general and certainly not the result of invasion from adjoining land. Furthermore, the yield was not increased as a result of fallowing.

The average yield of the cotton-fallow rotation for the 21-year period under consideration was 198 pounds of seed cotton per acre. The continuously cropped plot B–5–3, which had a mean loss from root rot of 46.3 percent, yielded 260 pounds of seed cotton per acre. The 2-year rotation A–4–D yielded 293 pounds, while the average yield of all rotations was 349 pounds per acre.

From a practical standpoint it must also be considered that half of the land is idle in this fallow-cotton rotation, and the yield of all the land on a yearly basis would be only one-half the figure given. It is difficult to account for the unusually low yield of cotton in this rotation. Perhaps location and fertility of the land may influence this to some extent, although no particular difference was observed between this and other rotations in field A–4. As a result of the observations made in this experiment it appears that, at least under the conditions at San Antonio, a 1-year fallow neither brought about a reduction in root-rot infection nor increased the yield of cotton.

TIME OF LAND PREPARATION

In the foregoing pages the effect of various rotational and cultural practices on the occurrence of cotton root rot has been discussed. The series of 2-year rotations in field B–6 afford an opportunity for the comparison of summer and fall preparation with spring preparation.

The results from a simple cotton-and-corn rotation, B–6–A, which was plowed in the summer preceding the cotton, may be compared with B–6–G which was identical except that it was plowed in February following both the corn and cotton crops. In making this comparison it should be recognized that these rotations are located some distance apart, and it seems likely that the uncontrolled and unknown factors influencing the severity of root rot have had a predominating influence. The 21-year mean losses in the spring-plowed rotation were almost four times as heavy as in the other, indicating that summer preparation of the land is decidedly the better practice. When these rotations are compared on the basis of their mean losses,

during the early 8-year period and during the last period, it is found that the disease increased more than eight times faster in the apparently better summer-plowed rotation than in B–6–G, which was spring-plowed. One factor that undoubtedly enters into this latter comparison and also into a number of others is that in those plots and rotations where only light losses occurred during the earlier years, there was greater opportunity for spread than in those where infection was heavy from the beginning. This fact is easily appreciated when the infection maps of the rotations are studied.

Early and late subsoiling ahead of the cotton crop may be compared in rotations B–6–B and B–6–H. The two rotations are similar in treatment except that the land was plowed and subsoiled in B–6–B as soon as practicable after removal of the crops, while in B–6–H these operations were delayed until February. As in the preceding comparison, the 21-year mean losses—10.1 and 34.7 percent, respectively—indicate the advisability of early preparation of the land, and their relative mean losses for the two 8-year periods decidedly reverse the interpretation. Summarizing the data available from this long-time series of 2-year rotations, it appears that the time of preparation of the land for the cotton crop has had little influence on the occurrence of the disease.

BORDERING TO PREVENT RUN-OFF OF RAINFALL

The rains at San Antonio are at times of torrential nature and often a large part of the precipitation is lost through run-off. Maintaining low borders of earth around the 1/5-acre plots A–4–7 to A–4–10, for the purpose of holding the water on the land until it could be absorbed, has been practiced since 1912. A simple rotation of cotton and corn, A–4–D, occupied two of these plots. No important influence upon crop production was noted. The 21-year mean loss of cotton from root rot in this rotation was 20.9 percent as compared with a similar mean loss in the simple cotton-and-corn rotation B–6–A of 12.7 percent. Their increases in losses during the second period as compared with the first period were from 18.3 to 31.3 percent and from 4.8 to 25.4 percent, respectively. Such uncontrolled factors as natural occurrence of the disease and soil difference probably overshadow any effects produced by bordering in this rotation.

EFFECTS OF PRECEDING CROPS

Considering the loss by disease from the standpoint of crop sequences, no significant consistent differences are apparent. Other factors, such as cultural treatment and length of the rotation, appeared to influence the prevalence of the disease more than the crop sequence. In two simple 2-year rotations the average 21-year mean loss following sorgo was 11.5 percent, whereas in a nearby rotation in which cotton followed corn the mean loss was 12.7 percent. The mean loss following milo in a similar rotation was 19.4 percent. Two 4-year rotations in which cotton followed sorgo had a mean loss of 5.6 percent. Three 3-year rotations in which cotton followed oats had a mean loss of 6.4 percent. An excellent comparison of the effect of the preceding crop is afforded by studying the 4-year rota-

tions A–5–C, A–5–D, and A–5–E. In each of these rotations cotton occurred twice and followed oats in one instance while in the other it followed milo. The loss following each crop each year may be compared throughout the 21-year period. Where cotton followed oats the mean losses were 23.6, 17.2, and 2.1 percent, respectively. For the same period the losses following milo were 24.7, 16.1, and 2.5 percent, respectively; in one case the losses were slightly higher following oats, and in the other two cases slightly higher following milo. The mean of the three plots shows a loss of 14.3 percent following oats and 14.2 percent following milo. The other rotations are scattered over such a range of soil conditions that it is impossible to make valid comparisons in most instances. From the results given and from observations it is believed that the preceding crop, other than cotton, used in these rotation experiments has exerted little, if any, effect in increasing or decreasing the severity of the disease.

ANNUAL FLUCTUATION IN LOSSES AND ERRATIC BEHAVIOR OF THE DISEASE

The erratic behavior of the disease is evident by studying the 21-year mean losses on plots within a rotation where each plot received identical treatment. In rotation A–4–G the mean loss was 10 percent. Plots 15 and 16 in this rotation had mean losses of 18.1 and 17.8 percent, respectively. Plots 17 and 18, the latter being adjacent to a continuously cropped plot of cotton, had mean losses of only 0.9 and 3.7 percent. In these cases where cotton occurred on a plot only once in 4 years, it is, of course, possible for certain plots to have been planted to cotton in years when the mean loss sustained on all plots was relatively high, whereas other plots might be in cotton in years when the mean loss on all plots was low. A study of the losses in all rotations for the years when plots 15 and 16 were in cotton as compared with losses for the years that plots 17 and 18 were in cotton indicates that part of this wide difference is due to this cause. The mean loss on all rotations for years when plots 15 and 16 were in cotton was 23.6 percent, whereas for the years when plots 17 and 18 were in cotton the mean loss was 16 percent. It is believed that these differences are not sufficient to account entirely for the wide variation within this rotation.

A study of the 2-year rotations A–4–A, A–4–D, and B–6–A and the 4-year rotation A–5–D affords further opportunity of observing the fluctuations of the intensity of the disease on different plots within the same rotation. The mean losses on plots within each of these rotations differed appreciably. In the case of the 2-year rotations the first three showed much greater mean losses for the plots cropped to cotton during the odd years, while in the fourth rotation the losses were much greater on the plot cropped to cotton in even years. In the 4-year rotation A–5–D, wherein cotton occurred on two plots each year, there was an extreme range in mean losses from 26.6 percent for plot 12 to 12.8 percent for plot 14. These two plots received identical rotational treatment and were planted to cotton the same years. In the two 3-year rotations B–4–A and B–4–B there was also wide variation between mean losses of the plots within each rotation. Here the plot having the lowest mean

loss in rotation B–4–A was cropped to cotton the same years as the one having the maximum mean loss in B–4–B. Figure 5 shows not only the nonuniformity between plots within several rotations but also the tendency of the disease to be more severe in certain areas than in others, irrespective of treatment.

The variation in the natural occurrence of the disease is further apparent when fields A–5 and B–6 were compared. In field B–6 it was observed that the loss increased toward the south regardless of treatment. The slope of the land is to the south, and the deeper soil with higher water-holding capacity may account to some extent for this condition. Whatever the cause, the tendency remains, and rotations located lower on the slope, which include the commonly supposed beneficial practices, had higher losses than the untreated rotations. In field A–5 there appeared to be a tendency for the loss from the disease to be centered in rotation C, the amount of root rot decreasing in each direction from this center. While part of these differences may be due to treatment, as the root rot decreased

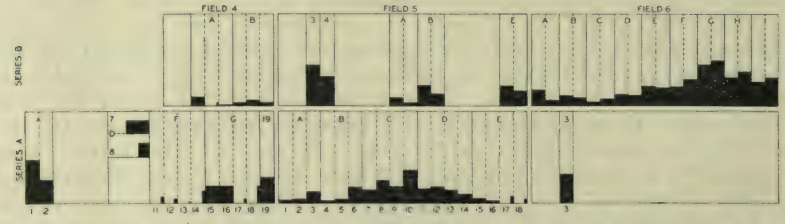

FIGURE 5.—Location of the different fields and rotations which include cotton. The shaded portions indicate the mean percentage loss from root rot on each plot for the 21-year period, 1912–32. Cotton does not occur where individual plots are not indicated.

from this center within rotations C and D, it appears that some conditions other than the rotational treatments account for the varying degree of loss.

The annual fluctuation of the disease in a given rotation often was found to vary within wide limits. An important and perhaps dominating influence may be the climatic variations. However, the trend of individual rotations did not consistently follow the trend of the average of all rotations. In rotation B–6–G the loss in an extreme case varied from 100 percent in 1916 to 23.2 in 1917 and only 8.5 in 1918. During the same years the average loss for all 2-year rotations was 20.0, 8.8, and 13.6 percent, respectively. These inconsistencies emphasize the erratic behavior of the disease and the futility of drawing conclusions from a few plots or for short periods.

INFLUENCE OF PRECIPITATION UPON LOSSES FROM ROOT ROT

It has been observed that losses from root rot are usually greater during seasons of moderate to high rainfall and especially so when this rainfall is well distributed throughout the growing season. A study of figure 6, which is a graph of the seasonal rainfall (March to October, inclusive) for each year from 1915 to 1932, inclusive, and of the mean root-rot losses in the rotation fields for the same years, shows a good correlation for the years 1916 to 1921, inclusive, and for 1925, 1926, and 1927. For the other years there appears to have

been little relationship. However, a study of daily precipitation records indicates the cause for this apparent lack of correlation. An analysis of the conditions of the 2 years 1922 and 1923 serves as an example. The total seasonal rainfall for the 2 years was 26.12 and 18.39 inches, respectively, while the mean root-rot losses were 8.1 and 41.9 percent, respectively. Precipitation during March, April. May, and June of 1922 was excessive, totaling 20.11 inches as compared with a normal for those months of 10.90 inches. The total rainfall from June 21 to October 21, 1922, inclusive, was only 1.21 inches, and consisted of scattered showers which were of no value in increasing available soil moisture. The result of this type of rainfall distribution was to cause cotton plants to make vigorous growth during the early part of the season. As a result of the dry, hot weather which followed, the soil moisture was so depleted that throughout the remainder of the season the plants suffered severely from drought. During the period when the root rot ordinarily makes its greatest advance, therefore, the soil moisture was reduced to the critical limit for plant growth.

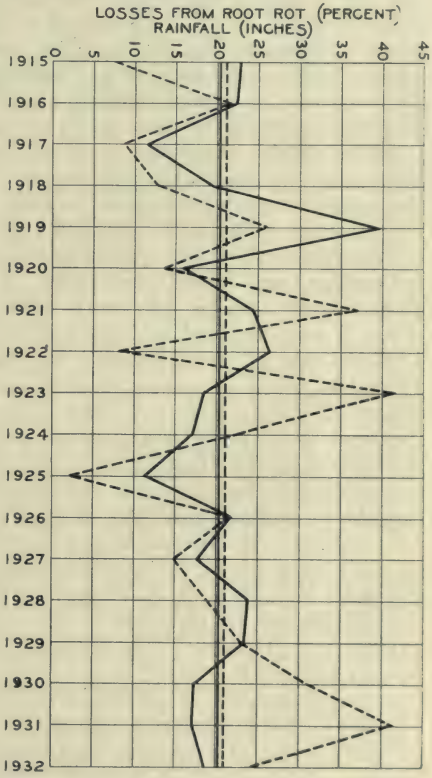

FIGURE 6.—Influence of precipitation on root-rot. The solid line shows rainfall from March to October and the dotted line root-rot losses. The means of each are shown by the straight lines.

Rainfall distribution in 1923 was very different. For the first 4 months, beginning with March, the total precipitation was 1.57 inches below normal. The plants were subnormal in size because of the inadequate supply of soil moisture. Precipitation was above normal for each of the 3 succeeding months, July, August, and September. The longest period without effective rains was 36 days, from July 22 to August 26. Although the soil-moisture conditions were favorable for plant growth the latter part of the season, excessive vegetative growth was restricted, due to the check to which the plants were subjected while young. On the other hand, the conditions evidently were favorable for the continuous growth and spread of the root-rot fungus. Seasonal distribution of rainfall was likewise favorable for the years 1930, 1931, and 1932.

DIAGRAMMATICAL RECORDS

Beginning in 1916 and continuing through 1932, the exact location of the infected areas on each plot, as indicated by wilted or dead

cotton plants, was determined by field measurements at the close of each season. These measurements have been transferred to diagrams, in order that a record of the location and spread of the root-rot disease might be available for study in connection with the statistical records. The diagrams showing the plots planted to cotton in the A series each year of the period, except 1928, are grouped together on the first sheet of figure 9 (at the back of this bulletin). All cotton plantings were destroyed by hail in 1928. The diagrams for series B for all the years of record are similarly grouped on the second sheet of figure 9. This permits a comparison of the behavior of the disease for a continuous period of 17 years, not only from season to season within each rotation but also its behavior in different portions of the fields.

From these diagrams it is apparent that while there has been some root rot in every plot on which cotton has been grown within the period covered by these records, there are certain plots in which the disease invariably appeared every time they were cropped to cotton, while there are others in which it appeared only intermittently. Examples ar found in plots A–4–11 and A–4–15 of rotations A–4–F and A–4–G. A small spot of infection occurred in A–4–11 when it was cropped in 1916, but when planted to cotton in 1920 and 1924 no plants were killed. No cotton was grown on this plot in 1928, but when in cotton in 1932 a small spot of infection again appeared in practically the same location as noted in 1916. From the locations of the infected areas in the adjoining plots in rotation A–4–D it seems likely that this small spot may have been a continuation of the previous infections. The disease was apparently unable to spread, nor was it continuously maintained in this plot. In contrast, the disease was maintained, independently of infection in adjoining plots, in A–4–15, which was cropped to cotton during the same seasons as A–4–11 and which for all practical considerations was subjected to identically the same crop sequences and cultural practices. However, the disease has not advanced into the east 50 feet of this plot.

An opportunity is afforded in certain instances of observing the tendency of the disease to persist in definite limited areas, regardless of the period of rotation, crop sequence, or cultural treatments involved. A spot which was confined to the west 25 feet of the south four rows of A–4–12 and which has never crossed into the adjoining plot A–4–13 was present each time cotton was planted on the plot. In January 1932 this area and two others were excavated in an endeavor to discover the reason for this persistent hold-over. At a depth of from 18 to 22 inches the root of some tree was found, in a state of advanced deterioration, running diagonally across the corner of the plot. It was traced through the soil from a point approximately 20 feet from the west end of the south row to a point about 8 feet from the west end of the third row. Occasionally a small piece of the dead tree root was found on which the root-rot fungus could be detected. During the process of digging, one small group of old, well-browned sclerotia was found.

In 1917, at a point 25 feet from the east end of the north row of A–4–14, four plants were dead at the end of the season. Four years later when again cropped to cotton this point was the center of a

small dead area. In 1925 drought prevented a stand, and a clean fallow was maintained throughout the year. When cropped to cotton in 1929 the spot appeared again, slightly larger than in 1921. Excavation in 1932 revealed dead roots of cotton plants of the season of 1929 and dead roots of some tree which had been removed prior to 1905. Mycelial strands of the root-rot fungus were found on both kinds of roots. A very small spot 20 feet from the east end of the north row in A–4–17 first appeared in 1922 and recurred in the identical spot in 1926 and in 1930. Again an area centered 65 feet from the east end of the south half of A–5–1 reappeared at each recurrence of the cotton crop except in 1922. Other areas of infection occurred in this plot, but each time in a different location.

A very few plants were dead in the north row of A–5–16, centered at 120 feet from the east end, in 1917. In 1919 only about 5 plants died at this spot. Again in 1921 and in 1923 cotton was killed in this location, but a considerably larger area was involved. Although 1925 was exceptionally droughty and relatively very few plants died, this spot manifested itself by just one dead plant. In 1927 there were no dead plants near this point, but during the 1929 season the spot reappeared, 7 plants dying in the north row and 2 plants in the adjacent row. No symptoms of the infection were noted in 1931. This spot was among those excavated in January 1932. The roots of several of the 1931 cotton plants were diseased below a depth of approximately 16 inches, although apparently healthy above that depth. At a depth of 20 inches the remains of old tree roots were found. Although so completely decayed that small fragments were extracted from the soil with great difficulty, brown mycelial strands of *Phymatotrichum* were discernible on their surfaces.

Small pieces of this root, as well as of those excavated from plots A–4–12 and A–4–14, were placed on moist filter paper in tin containers and taken to the station laboratory for study. Since sterilization of these highly porous root fragments by any of the conventional methods would have killed any fungus within them, as certainly as that on their exterior, they were placed unsterilized on agar in Petri dishes and incubated at approximately 30° C. The sclerotia found while excavating A–4–12 were similarly placed on agar and incubated. New growth of the fungus was plainly visible from the ends of the old strands and from the broken ends of the root pieces within 36 hours from the beginning of their incubation. After about 60 hours sufficient growth had been made to permit sectional agar transfers. Pure cultures of *Phymatotrichum omnivorum* (Shear) Dug. were thus obtained, and sclerotia were produced in soil cultures. Inoculations were made, infections produced, and the organism again recovered from the inoculated material. The sclerotia found in plot A–4–12 failed to germinate.[4]

The data recorded as a result of the excavation of these definitely outlined hold-over spots suggest that the causal organism of the disease had been able to persist as a saprophyte on the remaining roots of native woody plants which had been removed from these

[4] The laboratory work was done by L. G. McLean, scientific aid, Division of Cotton, Rubber, and Other Tropical Plants, U.S. Department of Agriculture.

fields not less than 27 years previously. The rotation and tillage methods practiced in these experiments had little, if any, effect in controlling this relatively inactive stage of the fungus. These results further substantiate the conclusion drawn by the writer in a previous paper (*10*). They also emphasize the fact that wilted and dead plants, while being practically the only aboveground indicators available for determining areas of infection, undoubtedly fail to reveal many deep-seated spots which may reappear after several seasons of apparent inactivity (*7*).

It is evident there are some locations which for some reasons are favorable for the invasion and continuation of the causal organism, while other areas undoubtedly offer no encouragement for the advance or hold-over of the disease. The small isolated spots already pointed out are good examples of conditions not favorable for the spread of the disease. By following the trend of the disease in field A–5 from plots 6 to 15, inclusive, an area which extended diagonally down from left to right appeared to be unusually favorable, while the areas at the northeast and southwest corners of this group of plots, though at times lightly infected, indicated a definite tendency to withstand a serious invasion of the disease. There were areas of considerable size at the east ends of plots A–5–5, A–5–6, A–5–7, and A–5–8 and at the west ends of plots A–5–13, A–5–14, and A–5–15 on which no plants were recorded as dead from root rot during the 17 years covered by these diagrams. The consistent absence of the disease from this particular area also confirms the belief that uncontrolled factors played a much greater part in the occurrence of root rot in these rotations than did the controlled factors.

In 1919 Scofield showed that over a period of 3 years, under continuous cropping to cotton, root rot did not always recur from year to year in the same spots (*13*). The conditions recorded for plot B–5–4 of these experiments for the years 1916, 1917, and 1918 were specifically cited. This fact is made apparent by observing the two small but definite spots in the west third of this plot which remained green in 1923. On the other hand, in 1924 these two identical areas were completely killed, while only a light mortality occurred on the plot as a whole. The dead and live areas, respectively, on plots B–5–3 and B–5–4 in 1931 very strikingly became the live and dead areas, respectively, in 1932. However, the fact that cotton does often die in the same spots in successive years on continuously cropped fields is definitely shown. An example is plot B–5–3 during the years 1916 to 1921, inclusive. A study of these rotation fields as a whole for the full period of the records indicates a tendency for the losses from the disease to increase and decrease uniformly over rather large areas from year to year, irrespective of rotation boundaries. However, considering the effects of climatic conditions, there appears to be no definite periodicity to these fluctuations.

In studying the behavior of the root-rot disease under conditions of various rotation periods as compared with continuous cropping to cotton, there appears to be a difference in favor of a rotation with nonsusceptible crops. In 2-year rotations this difference is less obvious than in longer ones. These results indicate that continuous cropping provided conditions favorable for the maintenance and spread of the disease. When mapping the location of dead plants

was started in 1916, plot A–6–3 had relatively small areas of infection at the west end and near the middle of the plot. It was the most lightly infected of the four continuous cotton plots. In 1917 these same spots were present and considerably enlarged, and another spot appeared at the east end of the plot. The disease indicated a strong tendency to center around these areas throughout the duration of the experiment. After 1921, by which time practically the entire plot had become involved, the losses on this plot followed quite closely the trend of the losses on the three other continuously cropped plots.

The combined results from the 2-year rotations failed to indicate any appreciable control of root rot. In the corn-cotton rotations on the north portion of the field B–6 the disease gradually but persistently spread from a few small scattered spots in 1916 until by 1923 a large percentage of the cotton was being killed. The disease

FIGURE 7.—Cotton killed by root rot in the 2-year rotation A–4–A, in which the land is held in clean fallow for 17 months between cotton crops. More than 80 percent of these plants had been killed before mid-August. (Photographed Oct. 9, 1931.)

behaved in the rotations on the south half of field B–6 very much as it had on the continuously cropped plots. In the 4-year rotations A–5–C, A–5–D, and A–5–E, in which cotton recurred on the same plots every second year, the tendency also was for the plant losses from the disease to increase progressively.

The results shown in the fallow-cotton rotation at the north end of series A (rotation A–4–A) are worthy of special consideration. There was very little loss of cotton on these two plots during the first years. Subsequently, however, the infection spread rapidly, and during the last two-thirds of the period of record the losses have been consistently as high as on the worst of the continuously cropped plots. The condition shown in figure 7 has become strikingly characteristic of the behavior of the disease in this rotation during the latter years of these experiments. In a series of experiments which were conducted at this station in field C–5 since 1927, to test the effect of various periods of fallow on the control of root rot, similar results were obtained. In 2 cases where cotton followed 1 year of clean fallow the root rot losses were 43.1 and 35.9 percent. In 4 cases where 2 years of fallow preceded the cotton

there was an average loss of 26.2 percent, and where 3 years of fallow preceded the cotton in 5 cases the average loss was 24.1 percent. One plot held fallow 4 years and then planted to cotton in 1931 suffered a loss of 24.5 percent, while on another fallowed 5 years and planted to cotton in 1932 there was a loss of 23.9 percent of the plants. Holding the land in clean fallow as practiced in these experiments did not prove effective as a means of controlling root rot, apparently on account of the frequency of persistent, deep-seated infestations.

In the 3-year rotation A–5–B it is interesting to note the definite relationship between the dead areas on plot A–5–6 and those in the adjoining plot A–5–7, which is part of a 4-year rotation in which cotton recurs every 2 years. This continuity of pattern is strikingly apparent in those years when both these plots were cropped, as 1920,

FIGURE 8.—Cotton as it appeared October 9, 1931, in a 4-year rotation with oats, milo (followed by field peas for green manure), and close-drilled sorgo. Less than 2 percent of the plants on this plot were killed by root rot.

1926, and 1932. Plot 14 in rotation B–4–A is also worthy of note. No plants died on this plot in 1917 or in 1920, but when cropped again to cotton in 1923 the entire east 75 feet of all rows was killed. The 3 following years that cotton occurred on this plot the same area was definitely outlined by dead spots, although it was not again so completely killed out. A relatively large infested area toward the west end of plot 18 of rotation B–4–B disappeared entirely in 1922, after having appeared in both 1916 and 1919. This spot did not again appear until the season of 1931, when a few scattered plants died within the original area.

The picture presented by the 4-year rotations A–4–F and A–4–G indicates that a deep-seated infection existed throughout about a third of the area of plots A–4–15 and A–4–16, wherein more or less of the stand of plants was killed each time cotton was planted. It is very evident that under the conditions prevailing in this group of plots the disease was unable to spread far from the original

sources of infection. Figure 8 is a characteristic view of one of these plots on which cotton is grown only each fourth year.

Either 3- or 4-year rotations of cotton with nonsusceptible crops appear to have been successful in holding down the loss from root rot, but neither was successful in eliminating the deep-seated infections.

SUMMARY

A series of rotation and tillage experiments at the United States San Antonio Field Station afforded an opportunity of observing the behavior of the cotton root-rot disease under various crop sequences and cultural treatments. The losses caused by the disease, as indicated by the percentage of plants killed, was recorded in connection with a total of 27 separate experiments over a period of 21 years.

The location of plants killed by root rot in each of these experiments was recorded accurately on diagrammatic maps each year, and these provided a means of studying the occurrence and distribution of the disease throughout the 17-year period 1916–32.

In many instances the natural occurrence and maintenance of the disease in the soil has exerted a greater influence on the prevalence of the disease than the rotational and cultural treatments applied, particularly in the case of the shorter rotations. In many instances the cause or causes have not been clear, although deep-seated, dead host material on which the fungus was able to maintain itself over long periods has appeared to have been a factor. Also the physical character, chemical composition, water-holding capacity of the soil, and the variation in the original infection in the different plots have materially influenced the extent of injury sustained.

In these experiments 2-year rotations of cotton with nonsusceptible crops have proved of very little value in the control of root rot, 3-year rotations appear to have been slightly more effective, while in 4-year rotations the disease has been effectively checked though not eliminated.

In one experiment the disease was maintained and spread as effectively where the land was cropped to cotton only in alternate years and was held in clean fallow for a minimum period of 17 months as when the land was cropped to cotton each season.

Neither barnyard manure nor green-manure crops proved of value in combating the losses from root rot.

Both the statistical data and the diagrams indicate that subsoiling as practiced in these experiments had little, if any, influence on the occurrence or spread of the fungus. Similarly, it appears that the time of preparation of the land, plowing, or subsoiling had no appreciable effect on the activity of the causal organism.

Cotton follows either corn, milo, oats, sorgo, or Sudan grass in the various rotations studied. The records available indicate that any difference that may exist between these crops in their effect on the behavior of the root-rot fungus was completely masked by the uncontrolled factors.

The behavior of the disease is shown to be extremely erratic, both by comparing similar treatments in different rotations and by

studying identical treatments on different plots within a rotation. Certain effects appeared as the result of some treatments when considered for a period of a few years, but they failed to continue, or were reversed, over a longer period. This emphasizes the danger involved in interpreting results obtained from experiments of short duration.

The virulence of the disease appeared to be closely correlated with the availability of soil moisture.

The diagrams made each year have provided a graphic record of the exact location of all areas on which cotton plants were killed by root rot from 1916 to 1932. These diagrams offer evidence indicating that:

Root-rot infection was inherently more prevalent and active in certain well-defined areas than in other adjacent areas, regardless of the treatments applied. The disease spread readily in some areas, was present but spread little in others, and did not occur at all in certain areas during the 17-year period.

Centers of infection persisted over long periods, irrespective of treatment as regards rotation or cultural practices. Excavation in small persistent centers produced evidence substantiating the theory that the fungus maintains itself saprophytically for long periods on deep-seated host material.

There has been a tendency for the infection to spread from year to year until large areas are involved, then "break up", and in many cases revert to the original areas of infection. There has been no definite periodicity, however.

The behavior of the root-rot areas does not lend support to the theory that the disease is distributed by tillage implements or cultural practices.

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EXPLANATORY LEGEND FOR FIGURE 9, A AND B

Annual losses of cotton from root rot in the rotation and tillage experiments in series A and B, at the United States Field Station, San Antonio, Tex., shown graphically from 1916 to 1932. Light lines indicate cotton rows and the heavy, shaded lines indicate the portion of the rows where the plants were killed by the disease. Owing to the extreme drought occurring in 1925 no cotton survived on several plots, whereas on the others the percentage of stand was low, and those surviving made but a poor growth. No records were available for 1928, as the cotton crop was totally destroyed by hail in June of that year. For convenience of reference, the cropping program is indicated briefly at the left of each sheet.

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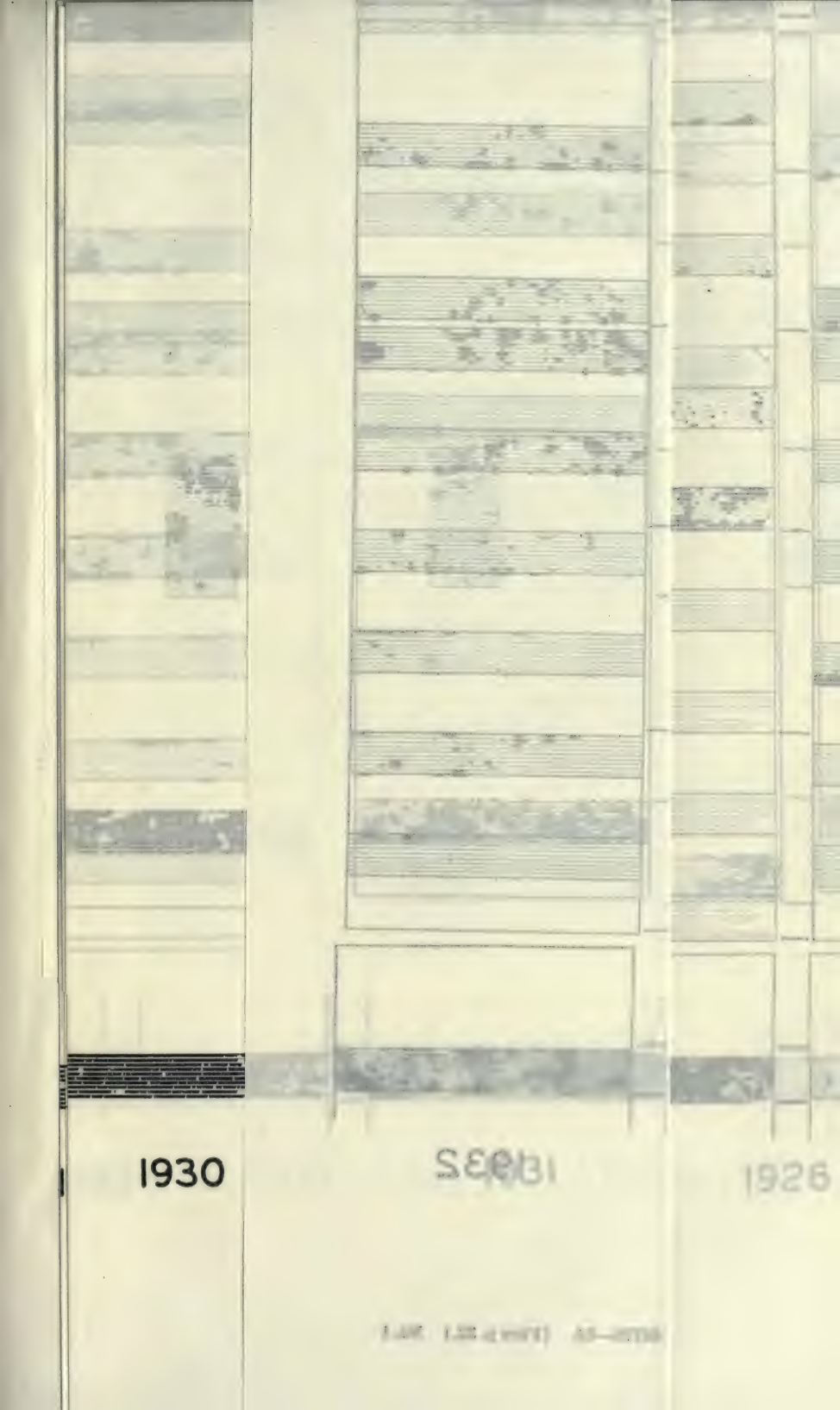
1930
1926

1926
1927
1928
1929

FIGURE 9, SERIES A

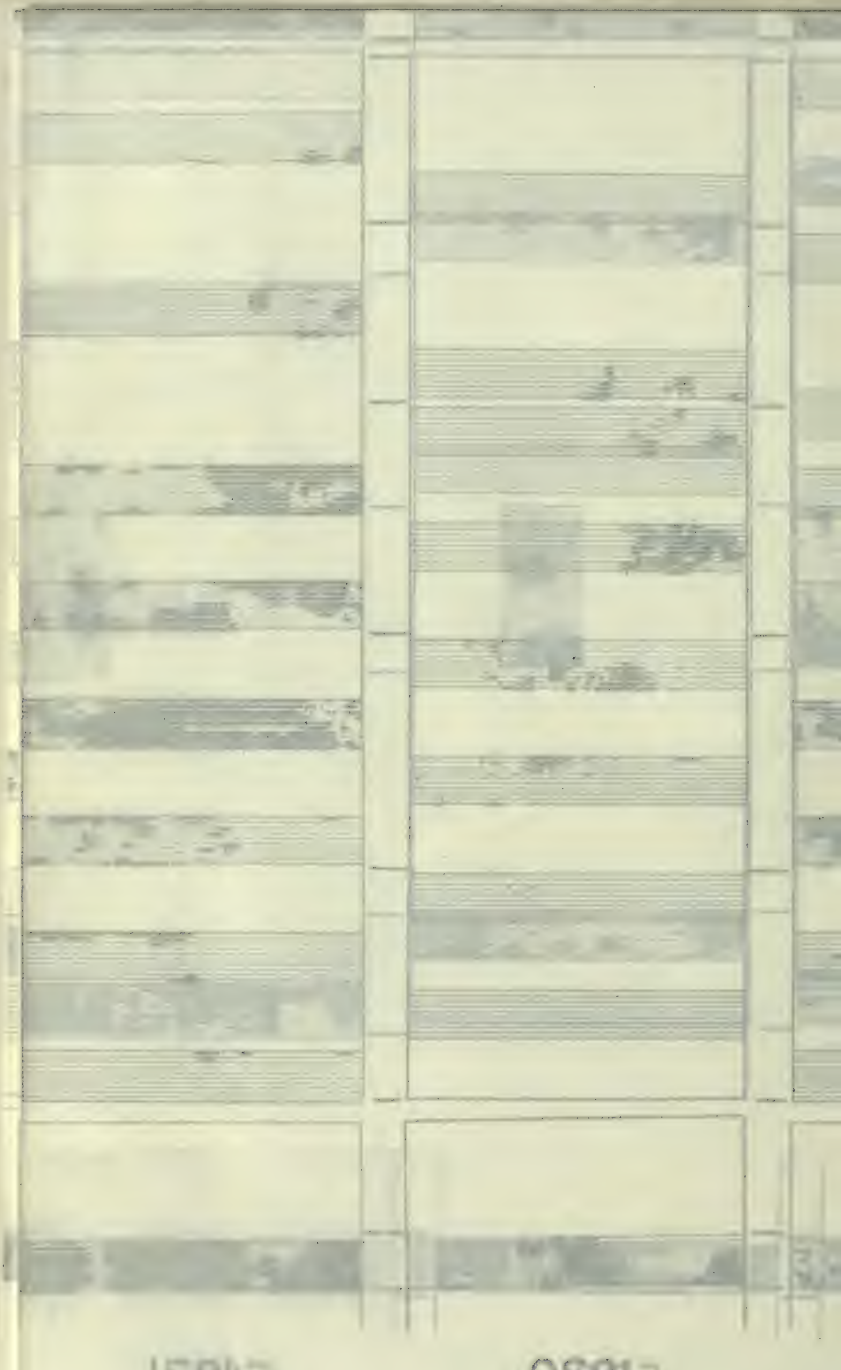

FIGURE 9, SERIES

WELD

FIELD A5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
A
COTTON
MILO
OATS
B
COTTON
MILO
OATS
MANURE
C
COTTON
OATS
COTTON
MILO
D
COTTON
OATS
COWPEAS
COTTON
MILO
MANURE
E
COTTON
OATS
COWPEAS-SUDSOIL
COTTON
MILO
MANURE-SUDSOIL
COTTON

1931
1932

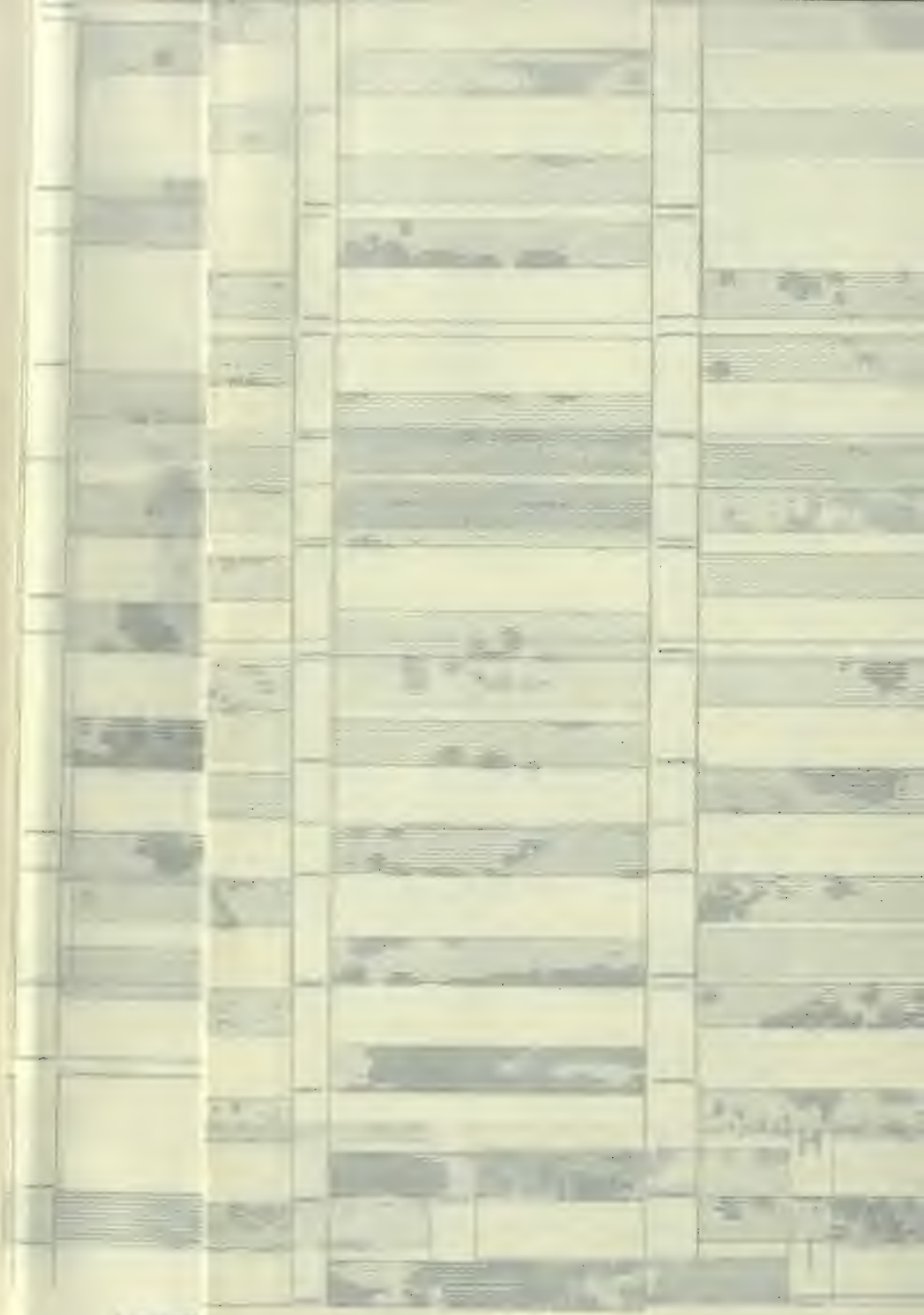

FIGURE 9, SERIES

A
COTTON
CORN
B
COTTON
CORN
C
COTTON
CORN
MANURE
D
COTTON
CORN
E
COTTON
CORN
F
COTTON
CORN
G
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CORN
H
COTTON
CORN
I
COTTON
CORN
RYE
1917
1918
1919

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Technical Bulletin No. 435 August 1934

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

COMPARISON OF SCABBED BARLEY, NORMAL BARLEY, AND YELLOW CORN IN DIETS FOR LAYING CHICKENS

By HARRY W. TITUS, *biological chemist*, and A. B. GODFREY, *junior poultry husbandman, Animal Husbandry Division, Bureau of Animal Industry*

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INTRODUCTION

After the harvest in years in which an appreciable portion of the barley crop becomes scabbed, there is a demand for information regarding the feeding of this diseased grain to livestock. The experiments herein reported were made with laying chickens, for the purpose of obtaining data on the comparative value of diets containing relatively large quantities, respectively, of scabbed barley, normal barley, and yellow corn.

REVIEW OF LITERATURE

Daugherty, Gossman, and Hendry, as reported by Haring (*3*),[1] compared the palatability of several grains for poultry and found that barley appeared to be much less palatable than wheat, yellow corn, or white yolo (a variety of grain sorghum developed at the California Agricultural Experiment Station), when these grains were fed from hoppers kept open for 2 hours before the chickens went to roost. Rintoul and Rugg (*8*) made a similar comparison of barley with other grains and reported that barley, when fed as "the grain at night", did not give so good results as Algerian oats, wheat, or mixed grains.

Lomax (*4*) compared barley and wheat as constituents of the scratch grain fed to White Leghorn pullets. He found no significant difference between these two grains in their effect on the production or size of eggs. He did find, however, that pullets receiving

[1] Italic numbers in parentheses refer to Literature Cited, p. 9.

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barley as a part of their diet ate somewhat more feed and produced a few more eggs than those receiving wheat. Nevertheless, wheat proved to be the more economical, since the feed cost per bird was greater for the barley group than for the wheat group and the return above feed cost was slightly in favor of the latter group.

Moore (*5*, *6*), compared barley and corn as constitutents of both the mash and scratch feed given to laying hens, as well as to chicks. He found that the pullets receiving barley laid eggs with lighter yolks than did those receiving corn but the shell texture of the eggs was not so good. The mortality among the former birds was only about two-thirds that of the latter. Chicks from eggs of the barley-fed hens appeared to be somewhat heavier than those from the other groups when the grains were fed in diets similar in all other ways. Moore's results demonstrate that barley can be safely substituted for corn in a diet for laying chickens, if provision is made for supplying enough vitamin A. Earlier experiments conducted by Hart, Halpin, and Johnson, as reported by Clark (*2*), had previously shown that this applies also to growing chicks.

Morgan (*7*) compared barley and corn as constituents of the mash fed to hens. He found little, if any, difference in the egg production and in the live weights. He did find, on the other hand, that the feed consumption of the hens receiving barley was greater than that of the hens receiving corn and that the feed cost per hen was greater.

Roche and Bohstedt (*9*) studied the effect of scabbed barley and scabbed oats on several classes of livestock and found that chicks fed scabbed barley did just as well as those fed normal barley. These investigators also report that scabbed barley fed to pullets, both in the mash and as a scratch feed, proved to be just as good as the undiseased grain, on the basis of live weight and number and weight of eggs produced.

No instances were found in which the all-mash system of feeding had been used or in which an experiment had been made to compare scabbed barley, normal barley, and yellow corn. In experimental work the all-mash system of feeding is to be preferred to the mash-and-scratch system because the former offers the chickens much less opportunity to select certain feeding stuffs than does the latter.

MATERIAL AND PLAN OF EXPERIMENT

The present comparison of the feeding value of diets containing relatively large quantites, respectively, of scabbed barley, normal barley, and yellow corn was made at the United States Animal Husbandry Experiment Farm, Beltsville, Md. Two feeding experiments were conducted, one for 100 weeks with Rhode Island Red pullets, and the other for 48 weeks with Single-Comb White Leghorn pullets. The first experiment was begun September 6, 1929, and the second 52 weeks later, September 5, 1930; both were continued until August 7, 1931.

At the beginning of each experiment strong, healthy pullets were obtained from the rearing range and were distributed, on the basis of live weight, among 4 pens, until each pen contained 22 pullets. Pens 1, 2, 3, and 4 contained Rhode Island Red pullets; pens 1–a, 2–a,

3–a, and 4–a, White Leghorn pullets. The birds in each pen were housed in a small colony laying house. Approximately 6,000 square feet of well-sodded grass range surrounded each house. At all times the birds had access to this range.

Four lots of scabbed barley [2] were fed. Lots 1 and 2 were moderately scabbed; the former contained no other grains, and the latter contained approximately 22.4 percent of other grains.[3] Lot 3 was slightly scabbed and contained approximately 2.1 percent of other grains. Lot 4 was very badly scabbed and contained approximately 13.8 percent of other grains. In all the scabbed-barley lots, nearly all the other grains consisted of oats. Lots 1 and 2 were fed until November 15, 1930, when they were exhausted, after which lots 3 and 4 were fed.

The composition of the diets is shown in table 1.

TABLE 1.—*Composition of all-mash feed mixtures fed to Rhode Island Red pullets during the first 52 weeks, Sept. 6, 1929–Sept. 5, 1930, and to the birds in both experiments during the last 48 weeks, Sept. 5, 1930–Aug. 7, 1931*

RHODE ISLAND REDS, FIRST 52 WEEKS

Ingredient	Pen 1	Pen 2	Pen 3	Pen 4
	Percent	*Percent*	*Percent*	*Percent*
Ground yellow corn	30.00			
Ground normal barley		30.00		
Ground scabbed barley (lot 1)			30.00	
Ground scabbed barley (lot 2)				30.00
Ground wheat	20.00	20.00	20.00	20.00
Rolled oats (feeding)	15.00	15.00	15.00	15.00
Wheat middlings	10.00	10.00	10.00	10.00
Dried buttermilk	6.00	6.00	6.00	6.00
Meat scrap (55 percent protein)	5.50	5.50	5.50	5.50
White fish meal	5.50	5.50	5.50	5.50
Alfalfa-leaf meal	3.50	3.50	3.50	3.50
Steamed bone meal	1.45	1.45	1.45	1.45
Ground limestone	1.45	1.45	1.45	1.45
Common salt	.72	.72	.72	.72
Anhydrous sodium sulphate	.55	.55	.55	.55
Flowers of sulphur	.22	.22	.22	.22
Anhydrous sodium thiosulphate	.11	.11	.11	.11
Total	100.00	100.00	100.00	100.00

BIRDS IN BOTH EXPERIMENTS, LAST 48 WEEKS

Ingredient	Pens 1 and 1-a	Pens 2 and 2-a	Pens 3 and 3-a	Pens 4 and 4-a
	Percent	*Percent*	*Percent*	*Percent*
Ground yellow corn	38.27			
Ground normal barley		38.27		
Ground scabbed barley (lots 1 and 3)[1]			38.27	
Ground scabbed barley (lots 2 and 4)[1]				38.27
Wheat bran	18.74	18.74	18.74	18.74
Rolled oats (feeding)	11.48	11.48	11.48	11.48
Meat scrap (55 percent protein)	7.76	7.76	7.76	7.76
White fish meal	6.79	6.79	6.79	6.79
Dried buttermilk	4.85	4.85	4.85	4.85
Alfalfa-leaf meal	4.21	4.21	4.21	4.21
Ground calcite	6.90	6.90	6.90	6.90
Anhydrous sodium sulphate	.50	.50	.50	.50
Common salt	.50	.50	.50	.50
Total	100.00	100.00	100.00	100.00

[1] Lots 1 and 2 were fed until Nov. 15, 1930, when they were exhausted, after which lots 3 and 4 were fed.

[2] Scabbiness caused by the fungus *Gibberella saubinetii*.

[3] Boerner, in the Handbook of Official Grain Standards of the U.S. Department of Agriculture (*1, p. 47*), defines the term "barley" as follows: "Barley shall be any grain which consists of 50 percent or more of barley, and contains not more than 25 percent of cereal grains of a kind or kinds other than barley."

The average composition of the yellow corn, normal barley, and scabbed barley used in these experiments is given in table 2.

TABLE 2.—*Composition of the yellow corn, normal barley, and scabbed barley used in experiments*

FIRST 52 WEEKS (RHODE ISLAND RED PENS)

Feed	Water	Crude protein (N×6.25)	Crude ash	Ether extract	Crude fiber	Nitrogen-free extract
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Yellow corn	12.80	8.00	1.20	3.81	2.11	72.08
Normal barley	12.73	11.40	2.53	2.08	5.46	65.80
Scabbed barley:						
Lot 1	12.95	12.25	2.94	2.17	6.22	63.47
Lot 2	12.42	13.81	2.93	1.86	6.55	62.43
LAST 48 WEEKS [1] (ALL PENS)						
Yellow corn	13.24	8.44	1.22	3.94	2.03	71.13
Normal barley	11.55	11.54	2.70	2.07	5.49	66.65
Scabbed barley:						
Lot 3	11.40	11.33	3.17	2.05	6.44	65.61
Lot 4	11.17	12.73	3.24	2.19	7.31	63.36

[1] Lots 1 and 2 of scabbed barley were used during the first 10 weeks of this 48-week period, and lots 3 and 4 the remaining 38 weeks.

In addition to feed-consumption, live-weight, and egg-production data, complete mortality records were kept as a basis for deciding whether mortality seriously affected the results. Records were kept of the total number of deaths which occurred during the experiment and the actual number of bird days for each pen.

EXPERIMENTAL RESULTS

The mortality data are given in table 3. The total number of possible bird days for 22 birds between September 6, 1929, and September 5, 1930, was 8,008, and for the same number of birds between September 5, 1930, and August 7, 1931, it was 7,392. However, attention is called to the fact that in the case of the Rhode Island Reds there was not the same number of birds in each pen at the beginning of the period between September 5, 1930, and August 7, 1931, since the number of deaths during the preceding period had not been the same in all the pens.

TABLE 3.—*Number of deaths and bird days in each pen during periods indicated, each pen initially containing 22 birds*

DEATHS

Rhode Island Reds				White Leghorns	
Pen no.	Sept. 6, 1929, to Sept. 5, 1930	Sept. 5, 1930, to Aug. 7, 1931	Total	Pen no.	Sept. 5, 1930, to Aug. 7, 1931
1	2	1	3	1-a	2
2	2	3	5	2-a	1
3	4	1	5	3-a	2
4	3	0	3	4-a	2

TABLE 3.—*Number of deaths and bird days in each pen during periods indicated, each pen initially containing 22 birds*—Continued

	BIRD DAYS				
1	7,763	6,690	14,453	1-a	6,865
2	7,903	6,373	14,276	2-a	7,090
3	7,806	5,878	13,684	3-a	7,288
4	7,773	6,384	14,157	4-a	7,020

The feed-consumption, live-weight, and egg-production data are presented in graphic form in figures 1, 2, and 3, respectively.

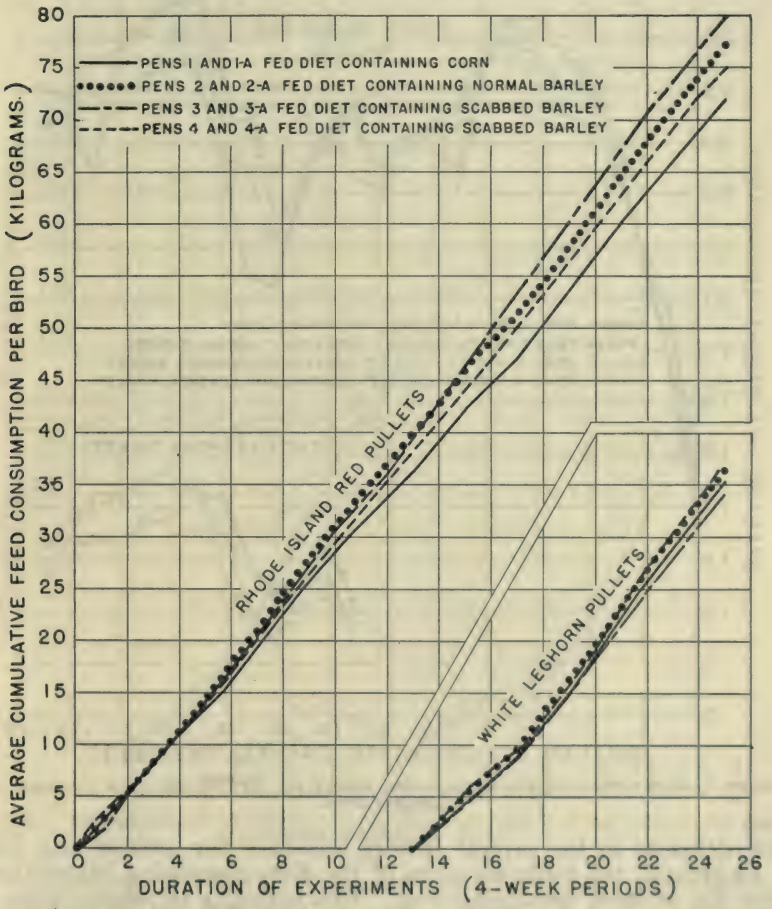

FIGURE 1.—Comparison of the average cumulative feed consumption per bird in the pens receiving the different diets.

DISCUSSION

One of the major nutritive differences between yellow corn and barley is that the former is a fair source of vitamin A, whereas the latter is a poor source. It is, therefore, logical to assume that one would obtain very similar results with these two grains, if the vita-

min A requirements of the chickens are adequately provided for. Although the chickens in the several pens received no cod-liver oil, they nevertheless were supplied adequately with vitamin A and vitamin D by the grass range and the sunlight, respectively.

A comparison of the data presented in table 3 shows that there were only slight differences in mortality among the comparable pens. It is clear, therefore, that the experimental results were not seriously affected by mortality. The data in this table also furnishes evidence that none of the diets, when fed to birds on range,

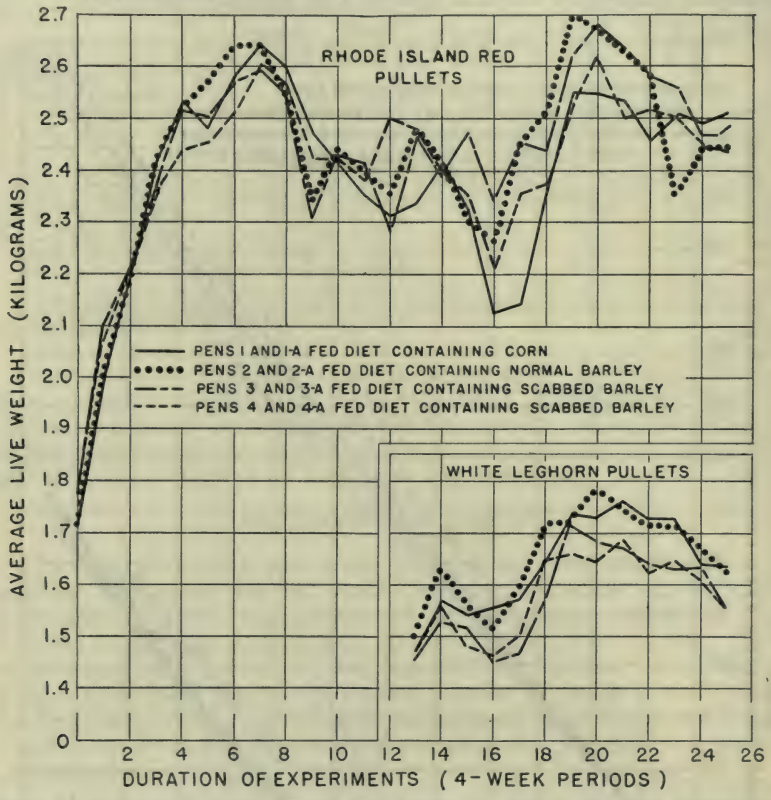

FIGURE 2.—Comparison of the average live weight per bird in the pens receiving the different diets.

was deficient in the several factors necessary for maintaining life.

In general, the birds ate more of the diets containing barley than they did of those containing corn. This is clearly shown in figure 1.

There were no significant differences in the quantities consumed, per head, of the three diets containing barley. During the first 60 weeks the maximum difference was between the two diets containing the scabbed barleys. This difference was approximately 1.7 kg (3.75 pounds) or about 4 percent of the feed consumed, and hence was less than is commonly found when two pens of chickens are placed on the same diet. A difference in feed consumption of

5 percent is commonly observed between duplicate pens of the size used in these experiments.

At the beginning of the sixty-third week new lots of scabbed barley were fed to pens 3 and 3–a, and to pens 4 and 4–a, respectively. In the first two pens the moderately scabbed barley was replaced by a lot of slightly scabbed barley, and in the last two pens the moderately scabbed barley was replaced by badly scabbed barley. Soon after these changes the rate of feed consumption in pen 3 increased slightly and that in pen 4 decreased to an equal, or slightly greater,

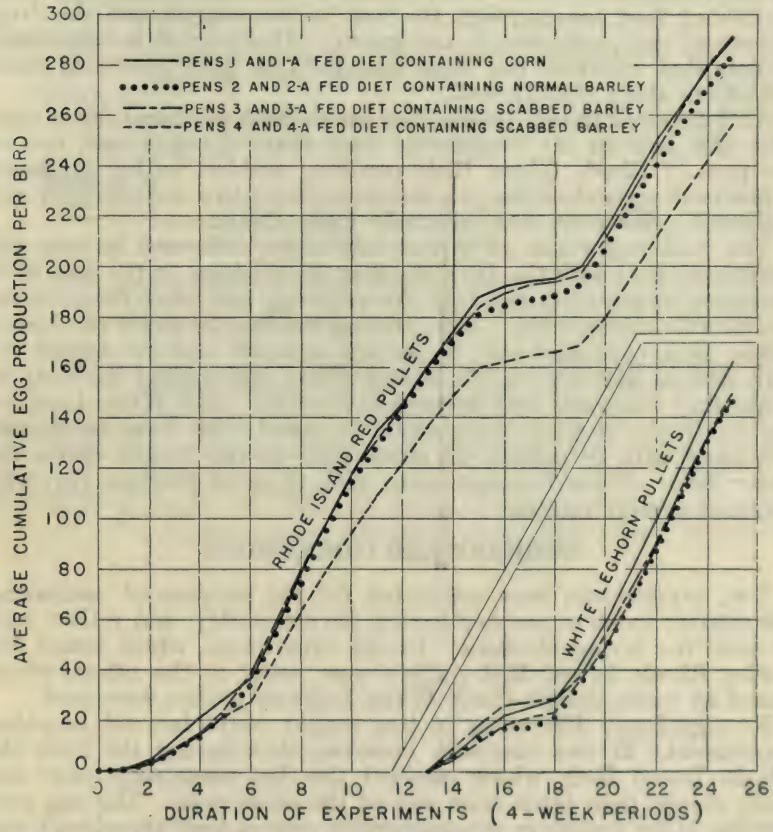

FIGURE 3.—Comparison of the average cumulative egg production per bird in the pens receiving the different diets.

extent; whereas the rate of feed consumption increased more rapidly in pen 4–a than in pen 3–a.

In view of these observations and the fact that all four pens of Leghorns ate nearly the same quantity of feed, it is clear that differences in feed consumption were not consistently due to differences in composition or degree of scabbiness of the several lots of barley.

Figure 2 shows that the average live weights of the birds in the four pens of Rhode Island Reds were remarkably close together throughout the experiment. After the molt the birds receiving corn

recovered their weight more slowly than did the birds receiving barley; however, the corn-fed birds laid practically as many eggs during their second laying year as did any of the others.

The live-weight curves of the White Leghorns also were rather close together throughout the experiment. However, all the Leghorn pullets lost weight some time between the fourth and twelfth week after they were placed on experiment. Incidently, during this same period their rate of feed consumption decreased somewhat, and following the twelfth week their rate of egg production dropped sharply and remained low for nearly 8 weeks. The cause of the decrease in rate of feed consumption, the loss in live weight, and the drop in rate of egg production is not known. However, it is interesting to note that whatever the cause was, the four pens recovered from the effects about equally well.

All but one of the six pens on the barley diets produced fewer eggs than the pens on the comparable corn diets. In this case, one of the pens of Rhode Island Reds receiving scabbed barley produced a few more eggs than the pen receiving corn; this difference in egg production, however, was relatively insignificant.

The most important, as well as consistent, difference between the results obtained with the diets was that the chickens on the corn diets consumed appreciably less feed, for each egg laid, than those on the comparable barley diets. Thus, during the first 52 weeks the Rhode Island Reds consumed only 87 percent as much feed per egg on the corn diet as they did on the barley diets; and during the next 48 weeks they consumed only 90 percent as much. The White Leghorn pullets, in the 48-week experiment conducted with these birds, also consumed only 90 percent as much feed on the former as on the latter diets. These findings agree with those of Morgan (7), who obtained similar results.

SUMMARY AND CONCLUSIONS

Two experiments were conducted for the purpose of comparing the relative value of scabbed barley, normal barley, and yellow corn in diets for laying chickens. In one experiment, which lasted 100 weeks, Rhode Island Red pullets were used; in the other, which lasted 48 weeks, Single-Comb White Leghorn pullets were used.

No significant differences in live weight were observed in either experiment. It was observed, however, that during the molt the Rhode Island Reds which received the diet containing corn lost more weight than birds from any of the other pens. The egg production of the pullets in the comparable pens in each experiment was quite similar, although the pullets in one of the pens of Rhode Island Reds which received scabbed barley did not lay so well as those in the other pens. In both experiments the chickens which received the diets containing corn showed a tendency to produce the most eggs and to eat the least feed. In both experiments the chickens receiving corn produced more eggs per pound of feed than did those receiving either normal or scabbed barley.

It is concluded that: (1) The diets which contained corn were the most efficient, since the pullets receiving them required only 87 to 90 percent as much feed per egg as those receiving the diets containing barley; and (2) scabbed barley whether slightly, mod-

erately, or very badly scabbed, may be expected to give essentially the same results as normal barley so far as maintenance of live weight, egg production, and economy of egg production are concerned.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

REFRIGERATED TRANSPORTATION OF BARTLETT PEARS FROM THE PACIFIC NORTHWEST

By E. D. MALLISON, *assistant marketing specialist*, and C. L. POWELL, formerly *junior physiologist, Division of Fruit and Vegetable Crops and Diseases*,[1] *Bureau of Plant Industry*

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INTRODUCTION

The investigation reported in this bulletin dealt largely with the factors affecting the cost of transporting precooled Bartlett pears and the effectiveness of different methods of refrigerating the fruit in transit. Cooling pears prior to transportation improves their keeping quality but at the same time adds materially to the cost of preparing them for market. If pears are already cooled down to good carrying temperatures at the time of loading it is easier to refrigerate them satisfactorily in transit than nonprecooled pears. It is reasonable to expect, therefore, that the load per car might be increased so as to reduce proportionately the cost per box of the refrigeration in transit and effect an important economy for shippers. At the same time this heavier loading would reduce the number of refrigerator cars required to move the crop, which would be an important consideration for the railroads.

That there is a close relationship between the temperatures at which pears are stored and transported and those at which they ripen

[1] Other members of the staff of the Division of Fruit and Vegetable Crops and Diseases who assisted in this investigation were C. O. Bratley, W. C. Cooper, M. P. Masure, M. H. Haller, J. C. Moore, and Henry Hartman. The cooperation and assistance of the various shipping organizations at Medford, Oreg., and Yakima, Wash., and of the various transcontinental railroad companies and refrigerator car lines that made these tests possible is deeply appreciated.

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has long been known. Magness, Diehl, and Allen[2] found that the storage life of Bartlett pears at 43° F. is approximately double that at 53°. At 36° the possible storage life is about double that at 43°, and at 31° it is about twice as long as at 36°.

SCOPE OF INVESTIGATION

These investigations were begun in 1928 and were continued during four seasons. Five complete transportation tests, involving 37 experimental car-lot shipments, were made from Medford, Oreg., and Yakima, Wash., to New York City. The shipments studied, as shown in table 1, comprised cars loaded respectively with 520, 640, 664, 720, and 744 boxes of pears and supplied with various quantities of ice and salt in transit. Information was obtained regarding the condition and temperature of this fruit at the time of loading, temperatures and ice meltage during transit, condition of fruit at destination, and its keeping quality during a subsequent storage period. For the most part the tests were made during periods of high outside temperatures in August and September, using the Bartlett variety, which is the first variety to be moved in large quantities from the Pacific Northwest. It was also considered that if the Bartlett, a variety having a short storage life, could be safely transported in the heavier load all other varieties could be safely shipped in the same sized load.

TABLE 1.—*Shipments of test cars of Bartlett pears from Medford, Oreg., and Yakima, Wash., to New York City during the 1928 to 1931 seasons*

Refrigeration	Size of load	Salt used	Test cars shipped from—				
			Yakima, 1928	Medford			
				1928	1929	1930	1931
	Boxes						
Precooled, standard refrigeration	520	3 percent		2	2	1	1
	520	75 pounds				1	2
	520	50 pounds			[1] 1	1	
	520	None	1				
	720	3 percent			1	1	1
	720	2 percent	1				
	720	75 pounds			[1] 1	1	1
	720	50 pounds			2		
	744	3 percent [2]				1	1
	640	do					1
	664	do		2			
	664	None		2			
Precooled, initial icing with two reicings.	720	None			2	1	
Nonprecooled, standard refrigeration.	520	5 percent			1	1	1
	520	3 percent		1			
	520	3 percent, 75 pounds.[3]				1	

[1] 100 pounds of salt found too large; changed to amount shown in third column.
[2] Boxes loaded on end; all others on side.
[3] 318 pounds of salt used on initial salting; 75 pounds at all other icing stations.

Supplementing this information, studies were made at point of origin and at destination on 67 commercial shipments of Bartlett, Bosc, and Anjou pears. Twenty-three of these shipments were loaded with 720 boxes to the car, and a few were made in pairs under comparable conditions, one of the cars being loaded with 520 boxes and the other with 720 boxes.

[2] MAGNESS, J. R., DIEHL, H. C., and ALLEN, F. W. INVESTIGATIONS ON THE HANDLING OF BARTLETT PEARS FROM PACIFIC COAST DISTRICTS. U.S. Dept. Agr. Tech. Bull. 140, 28 p., illus. 1929.

TERMINOLOGY

A number of terms commonly used in shipping circles and similarly used in this bulletin are defined below.

"Standard refrigeration" means that the refrigerator car was iced to capacity prior to loading and reiced to capacity at all regular icing stations while in transit. Icing stations are so spaced along the railroad lines that the cars can be reiced once, or possibly twice, each 24 hours. "Preiced" means that the car is iced to capacity prior to loading. "Initially iced; Do not reice" in connection with these shipments indicates that the cars were preiced and not reiced in transit. "Initial icing with two reicings" indicates that the car was preiced and reiced to capacity at two icing stations several days apart.

"Percent salt" designates the quantity of salt used in refrigeration, the weight of salt supplied at the initial salting being a percentage of the weight of the ice required to fill the bunkers to capacity and the same percentage of the ice added at each reicing station. In some cases instead of adding salt on this percentage basis a definite and empirically determined quantity of salt was added at each icing regardless of the amount of ice placed in the bunker. "Initial salting" indicates the first salting of the ice in a car.

The "bunkers" are the compartments at both ends of the car where the ice is placed. The "quarter-length position" is midway between the doors and the bunkers. The term "divided load" is used to designate a load having an open space of varying width between the doors, where it is braced with timbers to prevent shifting of the load. A "through or solid load" is one that is continuous between the bunkers. "Minimum load" is the least amount of weight that will be carried at the carload freight rate.

A "layer" is a course or stratum of the load parallel to the floor of the car and one package in height. A "stack" is a pile of packages extending from one side of the car to the other, parallel to the end of the car and one package in width. A "row" is a pile of packages extending lengthwise of the car, parallel to the sides and one package in width.

The condition of the pears is designated by the terms "hard", "firm", and "ripe." In these tests pears were considered hard when the average resistance of the pear flesh to the $\frac{5}{16}$-inch plunger of the pressure tester [3] was 12 pounds or above. When the average test was between 8 and 11.5 pounds the pears were considered firm; when below 7.5 pounds the fruit was termed ripe.

EXPERIMENTAL PROCEDURE

REFRIGERATOR CARS

The cars used in each test were selected from those regularly used in the shipment of pears and had been in service for 5 to 8 years. The insulation in the different cars varied from 1½ to 2 inches in thickness in the sides and ends, and from 2 to 2½ inches in the roof and floor. All cars were equipped with floor racks and insulated bulkheads. The bunker capacity was 10,600 to 10,700 pounds of chunk ice. Although there was a variation in the specifications of the cars used in the 1928 and 1929 tests, those used for the 1930 and 1931 tests were comparable.

[3] MAGNESS, J. R., and TAYLOR, G. F. AN IMPROVED TYPE OF PRESSURE TESTER FOR THE DETERMINATION OF FRUIT MATURITY. U.S.Dept.Agr.Circ. 350, 8 pp., illus. 1925.

THERMOMETERS

Electrical resistance thermometers were used to obtain fruit and air temperatures within the cars. The sensitive part or bulb of the instrument was inserted into a fruit or hung in the air at desired locations in the car. Leads from these bulbs were connected to a master cable which was carried out of the car through a thin doorplate placed at the top of the doorway and thence to the running board on the top of the car, as shown in figure 1. Readings were made by connecting the end of the master cable to an indicator or reading box equipped with a suitable selector switch by which the electrical resistance in any of the 12 bulbs could be determined. The indicator box is a modified Wheatstone bridge utilizing a sensitive galvanometer. Changes in the temperature of the bulb produce a corresponding change in the resistance of the coil in the bulb, which the indicator registers directly in degrees Fahrenheit. As a slight variation exists in the different instruments, calibrations of individual bulbs and indicators are necessary for accuracy. It will thus be seen that the instruments are so constructed and placed that temperature readings may be obtained at a number of places within the car without opening the doors. In the tests under discussion, readings were made at intervals of 4 to 6 hours. Outside air temperatures were obtained at the same time with a mercury thermometer.

In the 1928–29 tests fruit temperatures were obtained in the center row at the bottom, middle, and top layers of the quarter-length and doorway stacks and in the top and bottom layers of the stack next to the rear bunker. Air temperatures were taken at the top and bottom of the load at the doorway and rear bunker. Thus, extremes of temperatures as well as average conditions in the load were determined. However, in the 1930 and 1931 tests, thermometers were placed in the next-to-the-top layer at the quarter-length and doorway stacks instead of in the middle layer. This change was made because it was found in the earlier tests that the keeping quality of the top-layer pears was sometimes impaired by the higher temperatures in the top part of the load. It therefore became desirable to ascertain whether or to what extent the next-to-the-top layer is similarly affected.

EXPERIMENTAL FRUIT

It is impractical to attempt to draw conclusions from apparent effects on fruit of unknown or uncertain history, such as the average commercial shipments. In this work, therefore, reliance was placed on the observation of carefully selected comparable small lots of known history which were placed in representative positions in the different experimental cars.

The fruit selected for this purpose was usually taken from 3 or 4 normal trees and was picked at the usual harvest time and placed immediately in cold storage and cooled to 32° F. All lots were handled in the same way and held under comparable conditions prior to shipment. During transportation the test boxes were placed at selected positions in the cars and after arrival were placed in cold storage for further study. Inspections of the fruit were made at the time of arrival and at intervals during the subsequent storage periods to determine quality and condition and the rate of ripening. The firmness of the pears was determined by the use of a pressure tester.

REFRIGERATION RECORDS

Except at the first icing, when the bunkers were filled to known capacity, observers accompanying the cars weighed the ice and salt used before they were placed in the bunkers. The amount of ice

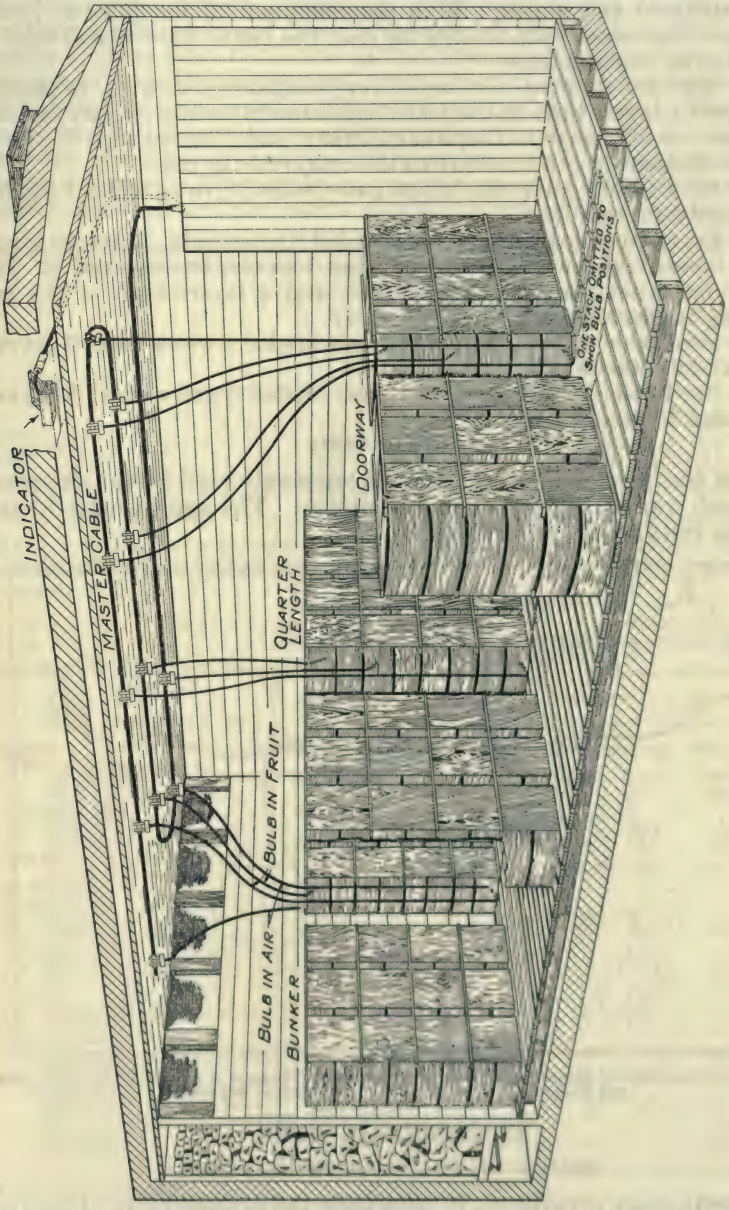


FIGURE 1.—Perspective view of the interior of a refrigerator car showing method of installing resistance thermometers in test cars loaded with pears with master cable connecting to indicator box on roof of car where all temperatures were read.

remaining in the bunkers at destination was estimated as closely as possible in all cases. The procedure was to pike the ice to a level surface and determine the proportion of the bunker space that it filled.

DESCRIPTION OF LOADS

Four different loads were compared with the standard load of 520 boxes. The 640- and 744-box loads were through loads, whereas the others were divided loads braced at the doorway. All the layers were stripped and nailed. With the exception of the 744-box load, in which the boxes were loaded on end, the boxes were loaded on the sides in the usual manner.

For the 520-box load, the boxes were loaded 8 rows wide, 18 stacks long, and 4 layers high in the last 6 stacks next to one bunker and in the last 5 stacks next to the other bunker, and 3 layers high in the 7 stacks adjacent to the doorway in the center of the car.

For the 640-box load, the boxes were loaded 8 rows wide, 4 layers high, and 20 stacks long.

For the 664-box load, boxes were loaded 8 rows wide, 18 stacks long, and 5 layers high in the last 6 stacks next to one bunker and in the last 5 stacks next to the other bunker, and 4 layers high in the remaining stacks adjacent to the doorway.

For the 720-box load, the boxes were loaded 8 rows wide, 5 layers high, and 18 stacks long.

For the 744-box load the boxes were loaded 8 rows wide, 3 layers high, and 31 stacks long.

ROUTE OF TESTS

Each test was made over the route commonly used by the shippers, and each varied slightly from the others. The approximate routes of these tests are shown in figure 2.

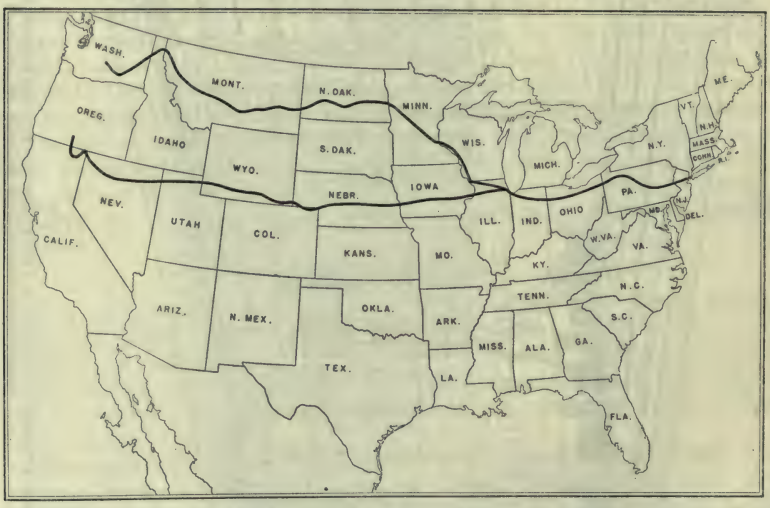


FIGURE 2.—Map showing approximate routes of experimental shipments of pears from Medford, Oreg., and Yakima, Wash., to New York City, 1928 to 1931 seasons.

EXPERIMENTAL WORK

HEAVIER LOADING OF PRECOOLED PEARS

A preliminary experiment to determine the practicability of heavier loading of precooled pears was made in September 1928. This test was a comparison of a 520-box load with a 664-box load. The results obtained with the heavier load were encouraging, so a second test

was made in October of the same year with a still larger load of 720 boxes. The results of this test were not conclusive because the weather was cool.

The next three experiments (1929, 1930, and 1931) were made with Bartlett pears shipped during the early part of the season, when weather conditions were more favorable, as shown in table 2. The results of these three tests showed that precooled pears, shipped under comparable conditions, reached destination at about the same stage of maturity when shipped in either 520- or 720-box loads. Conditions under which the tests were made varied each season, yet the relation between the 520-box and the 720-box loads in the tests remained about the same. The results of the test made in 1930, as shown in table 3, are typical of the results obtained in the other tests mentioned.

TABLE 2.—*Maximum, minimum, and mean outside temperatures in transit during the pear transportation tests of 1928, 1929, 1930, and 1931*

Origin of shipment	Year	Date started	Date completed	Outside temperature in transit		
				Maximum	Minimum	Mean
				° F.	° F.	° F.
Oregon	1928	Sept. 12	Sept. 25	91	36	57.0
Washington	1928	Oct. 13	Oct. 25	93	36	50.3
Oregon	1929	Aug. 29	Sept. 9	104	60	72.5
Do	1930	Aug. 18	Aug. 29	89	44	69.4
Do	1931	Aug. 14	Aug. 25	92	50	72.7

TABLE 3.—*Length of time, expressed in hours and in percentage of the transit period, during which the temperature of precooled fruit was within certain temperature ranges*

[Test conducted in August 1930]

Position of fruit and amount of salt added	Time[1] in transit during which temperatures of precooled fruit were within range of—							
	30°–35° F.		35°–40° F.		40°–45° F.		45°–50° F.	
	Hours	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*
Top layer:								
3 percent salt:								
520-box load	0	0.0	34	15.1	127	56.2	65	28.7
720-box load	0	.0	72	31.8	71	31.4	83	36.8
75 pounds salt:								
520-box load	0	.0	63	27.8	163	72.2	0	.0
720-box load	0	.0	72	31.8	154	68.2	0	.0
No salt:								
720-box load	18	8.0	33	14.6	64	28.3	111	49.1
Next-to-top layer:								
3 percent salt:								
520-box load	0	.0	161	71.3	65	28.7	0	.0
720-box load	78	34.5	94	41.6	54	23.9	0	.0
75 pounds salt:								
520-box load	44	19.4	182	80.6	0	.0	0	.0
720-box load	65	28.7	161	71.3	0	.0	0	.0
No salt:								
720-box load	34	15.0	69	30.6	123	54.4	0	.0
Bottom layer:								
3 percent salt:								
520-box load	126	55.8	100	44.2	0	.0	0	.0
720-box load	22	9.7	177	78.3	27	12.0	0	.0
75 pounds salt:								
520-box load	216	95.6	10	4.4	0	.0	0	.0
720-box load	226	100.0	0	.0	0	.0	0	.0
No salt:								
720-box load	58	25.6	168	74.4	0	.0	0	.0

[1] Total time in transit was 226 hours.

With precooled pears only a small difference was found between the temperatures at comparable positions in cars with 520- and 720-box loads when both received the same amount of refrigeration in transit.

Temperature differences between layers in the same car were generally less in the heavier loads. In the 520-box load the next-to-the-top layer was the second from the floor at the doorway and the third from the floor in the quarter-length and bunker stacks. In the 720-box load it was the fourth layer from the floor in all stacks, and therefore was nearer to the top of the car than in the 520-box load. Despite this, temperatures were slightly lower in the next-to-the-top layer of the 720-box load than in the next-to-the-top layer of the 520-box load, which indicates that there is not a definite or regular stratification of temperatures within the car regardless of the size of the load, as has been commonly believed. Typical examples are shown in table 3. The lower average temperature in the next-to-the-top layer of the 720-box load was doubtless due to the influence of the larger mass of precooled fruit in the heavier load.

The data in table 3 show the length of time the various layers of fruit were in certain ranges of temperature, and table 4 shows the comparative rate of softening of the fruit after being subjected to the temperatures shown in table 3. Comparison of these two tables indicates that the storage life of the pears after shipment in the 520-box and 720-box loads under comparable conditions was about the same. This, of course, was to be expected, considering the comparable transit temperatures and the subsequent comparable storage temperatures. The data in these tables indicate that in some instances the 720-box load might be slightly preferable from the standpoint of maintaining both lower transit temperatures and longer storage life for the fruit after arrival at destination. However, the differences that occur are neither sufficiently large nor consistent enough to justify concluding more than that the temperatures and the storage life of the fruit were about the same, no matter whether the fruit was shipped in the 720-box load or the 520-box load. The most pronounced difference was found at the time of the last two inspections with fruit from the top-bunker position of cars receiving 75 pounds of salt at each reicing en route. At these inspections the fruit from the 720-box load was 2.4 to 3.5 pounds firmer than that from the same position in the 520-box load.

TABLE 4.—*Comparative rate of softening of precooled pears from doorway and bunker positions in top layer during the 1930 test*

Item	Pressure test on—				
	Aug. 17 [1]	Aug. 28	Sept. 26	Oct. 20	Nov. 19
Doorway:					
3 percent salt:	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
520-box load	14.0	13.5	10.6	9.0	8.7
720-box load	14.0	12.5	11.8	----------	10.9
75 pounds salt:					
520-box load	14.0	13.0	13.0	11.5	10.4
720-box load	14.0	13.2	11.7	----------	11.3
No salt:					
720-box load	14.0	13.3	8.8	9.0	7.3
Bunker:					
3 percent salt:					
520-box load	14.0	13.7	10.3	----------	9.1
720-box load	14.0	----------	----------	----------	----------
75 pounds salt:					
520-box load	14.0	13.3	12.0	8.0	8.9
720-box load	14.0	14.2	12.0	11.5	11.3
No salt:					
720-box load	14.0	13.3	8.8	6.0	----------

[1] Date of loading test cars.

In the 3-year tests a comparison of the total average amount of ice placed in the bunkers and the amount melted in the refrigeration of the 520- and 720-box loads of precooled pears (table 5) shows that there was very little difference in the amount of ice melted by these two loads. In each instance an average of about 57 percent of the total amount of ice placed in the bunkers was melted, about 43 percent of the total being left in the bunkers and not utilized in the refrigeration of the pears.

TABLE 5.—*Quantity of ice placed in bunkers and amount melted in cars of precooled pears in tests made in 1929, 1930, and 1931*

Year of test	520-box load				720-box load			
	3 percent salt		75 pounds salt		3 percent salt		75 pounds salt	
	Ice in bunkers	Ice melted	Ice in bunkers	Ice melted	Ice in bunkers	Ice melted	Ice in bunkers	Ice melted
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1929	20,790	13,574			21,684	13,864	21,771	12,951
1930	19,701	10,291	20,202	12,542	19,031	9,585	19,485	9,449
1931	19,425	10,544	21,326 20,184	12,515 11,028	19,781	10,488	20,056	11,312
Average	19,972	11,470	20,571	12,028	20,165	11,312	20,437	11,237
Percent		57.4		58.4		56.1		55.0

These results were to be expected under the conditions of these experiments, since the amount of heat given off in the respiration of precooled fruit is comparatively small, and the larger amount of cold fruit in the 720-box load would be expected to help maintain lower temperatures for a longer period.

USE OF SALT AS AN AID TO REFRIGERATION

The use of salt with the ice in refrigerator cars has been general for several years. In commercial practice there is a variation in the amount used, depending largely upon the season of the year and whether the lading is precooled or not. The weight of the salt added is a stated percentage of the amount of ice necessary to fill the bunkers to capacity. The common practice with shipments of pears from the Pacific Northwest during the early part of the shipping season is to use 3 percent of salt when the fruit is precooled and 5 percent when it is not precooled. In most instances the largest percentage of the total amount of salt used in a trip is placed in the bunkers at the initial icing and only small amounts are added at reicings in transit. In the test made in 1928 between Medford and New York, for example, 571 pounds of salt was placed in the bunkers of a car containing 520 boxes of precooled pears. Of this amount 318 pounds was used at the initial icing. The remaining 253 pounds was distributed among 10 reicings at various stations en route.

When precooled pears are shipped during warm weather, fruit temperatures are lower at the time of loading than at any other period during transit. Consequently, under customary methods, the largest quantity of salt is added when least needed, making this a questionable practice.

Figure 3 shows that during a 48-hour period after the 318 pounds (3 percent) of initial salt was added, the drip water from cars loaded with precooled pears contained from 7 to 14 percent of salt, indicating that the salt was being rapidly removed from the car, and that during the last 8 days of the trip the 14 to 25 pounds of salt added at the reicing stations was not sufficient to replace that leaving the car in the drip water. It shows further that the amount of salt in the bunkers of the car diminished rapidly from 3 percent during the first few hours after the initial salting to a small fraction of 1 percent of the ice in the bunker during the last 5 days of the trip. This condition was correlated with the temperature in transit, for during the last 4 or 5 days of the trip the fruit and air temperatures in cars receiving 3 percent salt were approximately the same as in

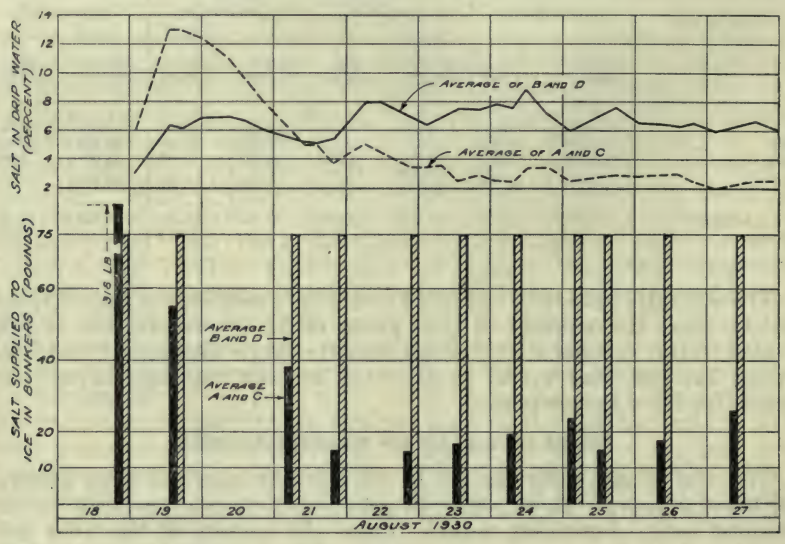


FIGURE 3.—Amount of salt in the drip water of cars *A*, *B*, *C*, and *D* (loaded with precooled pears) and the amount of salt supplied to the ice in the bunkers. All cars under standard refrigeration and salted at each icing; *A* and *C* with 3 percent, averaging 559 pounds per car; *B* and *D* with 75 pounds, averaging 825 pounds per car.

cars receiving no salt. A comparison of the temperatures obtained in cars shipped with 520- and 720-box loads receiving no salt, 3 percent of salt, and 75 pounds of salt at each reicing is shown in table 3, and the influence of these temperatures on the fruit is shown in table 4. Table 3 shows that lower temperatures were obtained in the cars receiving 75 pounds of salt at each reicing.

Since the temperatures in the car throughout the journey were directly related to the quantity and distribution of the salt in transit, different methods of salting were tried out in the experiments of 1929 and 1930. In some of the test cars the amount of salt used at the initial salting was reduced to 50, 75, or 100 pounds; in others the same amounts of salt were also used at each reicing station.

From the data obtained, 75 pounds of salt applied at each reicing station is apparently the most satisfactory amount to use with precooled pears. When this amount was used the air and fruit tem-

peratures in the bottom layer usually ranged from 30° to 35° F., whereas with 3 percent salt the fruit temperatures at the bottom of the bunkers were sometimes as low as 27° and air temperatures were 16° to 18° for a short period following the initial salting. The application of 100 pounds of salt at the initial salting and at each of the reicing stations reduced the temperatures too much, since they dropped nearly to the freezing point by the fourth or fifth day in transit. In this test it was accordingly necessary to omit the application of salt at two reicing stations in these cars and to use only 50 or 75 pounds at the remainder of the icing stations.

Under the modified practice of adding fixed amounts of salt at all reicings, temperatures in transit were more favorable. When 50 or 75 pounds of salt was placed in the bunkers at each reicing, the fruit temperatures of precooled pears usually varied between 35° and 45° F., whereas with 3 percent salt the temperature ranged as high as 50°. The more favorable temperatures (table 3) obtained with the larger amounts of salt at all reicings make it possible for the fruit to be kept longer after arrival at destination. Obviously, the use of 50 or 75 pounds of salt should be limited to shipments of precooled pears during the early part of the season when outside temperatures are high, and shipments later in the season should have the amount of salt materially reduced.

As shown in table 5, the ice meltage was practically the same in all cases. During the test of 1930, for example, the ice meltage in two comparable 720-box loads of precooled pears, one supplied with 75 pounds of salt and the other with 3 percent of salt at each reicing, was 9,449 and 9,585 pounds, respectively.

Nonprecooled pears require a salting treatment different from that of precooled pears. When the fruit has not been precooled it is desirable to remove as much of the field heat as possible immediately after loading. The use of 5 percent salt, which is the standard commercial practice, seemed to give the best results in such cases. A test was made in 1930 to determine whether the use of 318 pounds (3 percent) of salt at the first reicing and 75 pounds at all other reicings would give more satisfactory results than the use of 5 percent salt throughout, but no significant difference in results was obtained.

In 1929 a test was made to determine the possibility of shipping precooled pears without using salt. Two cars carrying a load of 720 boxes each were shipped under standard refrigeration without salt, and two similar cars were shipped under standard refrigeration with 3 percent salt. The results obtained in this test indicated that salt is desirable even with precooled fruit during warm weather. The fruit in the top layers of the cars shipped without salt was turning yellow in color and was getting soft on arrival, whereas the fruit in similar layers in cars shipped with salt was still green and firm.

TRANSIT CONDITIONS WITH PRECOOLED AND NONPRECOOLED PEARS

There is still a large tonnage of pears shipped from the Pacific Northwest that is not precooled because of lack of facilities at shipping points. However, the value of precooling has been amply demonstrated by previous investigations. Pentzer et al.,[4] conducted experiments

[4] PENTZER, W. T., MAGNESS, J. R., DIEHL, H. C., and HALLER, M. H. INVESTIGATIONS ON HARVESTING AND HANDLING FALL AND WINTER PEARS. U.S. Dept. Agr. Tech. Bull. 290, 30 pp., illus. 1932.

which indicated that the lower temperatures secured by precooling may be expected to add 1 to 2 months to the subsequent storage life of pears held at 31° F. beyond that which can be expected from nonprecooled fruit.

Magness and Diehl[5] found that Bartlett pears held at temperatures approximating those in cars thoroughly precooled prior to loading could be safely stored at 31° F. for periods of 30 to 45 days and ripen with good quality, provided the fruit had been promptly and thoroughly cooled. Bartletts held at temperatures approximating those in the top of nonprecooled cars were ripe at the end of a 12-day holding period, whereas fruit held at temperatures equivalent to those prevailing in the lower half of the load was generally suitable for holding up to 45 days at 30° to 31°.

In the investigations covered by this bulletin, tests were made each year to compare precooled and nonprecooled shipments of Bartlett pears. As the customary commercial procedure is to use 5 percent salt with nonprecooled shipments and 3 percent with precooled shipments, the various test cars accordingly received these amounts. The temperature of the warm fruit at the time of loading the cars ranged from 65° to 75° F., whereas the average loading temperature of the precooled fruit was between 32° and 34°, a difference of 33 to 41 degrees. During transit 6 to 7 days elapsed before the temperature of the nonprecooled fruit reached that of the precooled fruit, so that the former necessarily ripened much more rapidly than the latter while they were en route to market, a period of 9 to 10 days.

The results obtained in this phase of the investigation were about the same in each year's tests. The temperatures in the cars loaded with warm fruit were above 50° F. for about one-third of the time that the cars were en route and between 45° and 50° for the remainder of the time. Precooled shipments were between 35° and 40° for a short time, between 40° and 45° about 60 percent of the time, and between 45° and 50° approximately a fourth of the time, with none of the temperatures going above 50°. A typical example of the range of transit temperatures is given in table 6.

TABLE 6.—*Comparison of average fruit temperatures obtained in the top and next-to-top layers of 520-box loads of precooled and nonprecooled pears in tests made during August 1930*

Position of fruit and amount of salt added	Time[1] in transit during which temperatures of precooled and nonprecooled fruit were within the range of —											
	35°–40° F.		40°–45° F.		45°–50° F.		50°–55° F.		55°–60° F.		60°–65° F.	
Precooled:												
3 percent salt:	*Hr.*	*Pct.*	*Hr.*	*Pct.*	*Hr.*	*Pct.*	*Hr.*	*Pct.*	*Hr.*	*Pct.*	*Hr.*	*Pct.*
Top layer	34	15.1	127	56.2	65	28.7	0	0.0	0	0.0	0	0.0
Next-to-top layer	161	71.3	65	28.7	0	.0	0	.0	0	.0	0	.0
Nonprecooled:												
5 percent salt:												
Top layer	0	.0	0	.0	138	61.0	38	16.8	20	9.0	30	13.2
Next-to-top layer	0	.0	152	67.2	37	16.4	13	5.8	13	5.8	11	4.8

[1] Total time in transit was 226 hours.

A direct correlation was found between the condition of the fruit upon arrival at destination and its temperature during transit. The pears in the top layers of the nonprecooled loads generally arrived in a

[5] See footnote 2.

firm to ripe condition and ripened shortly after being placed in storage, whereas the precooled fruit from the top layers arrived in a firm to hard condition and remained firm after being in storage at 32° F. for 60 to 80 days. It was found, furthermore, that after arrival at destination, precooled Bartletts had a storage life 6 to 10 weeks longer than those that had not been precooled. Results obtained in 1930 are typical and are shown in table 7. In this connection, however, Hartman [6] has reported that Bartlett pears do not ripen with maximum dessert quality if held longer than 4 to 6 weeks in storage, even under ideal conditions, and Magness, Diehl, and Allen [7] found that while Bartletts could be stored 3 to 5 months under proper conditions, the longer the pears were held in cold storage the poorer the dessert quality of the ripened product. The poorer dessert quality was not noticeable until after 30 days in cold storage.

TABLE 7.—*Comparative rate of softening of pears from top layer of 520-box loads of precooled (3 percent salt) and nonprecooled pears (5 percent salt) during test made in 1930*

Item	Pressure test on—				
	Aug. 17 [1]	Aug. 28 [2]	Sept. 26 [3]	Oct. 20 [4]	Nov. 19 [5]
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Doorway:					
Precooled	14.0	13.5	10.6	9.0	8.7
Nonprecooled	14.0	12.6	7.1	[6] 4.5	[6] 6.9
Bunker:					
Precooled	14.0	13.7	10.3	----------	9.1
Nonprecooled	14.0	9.8	3.3	[6] 4.2	[6] 4.2

[1] Date of loading cars.
[2] Unloaded and placed in storage at 32° F.
[3] First inspection in storage.
[4] Second inspection in storage.
[5] Third inspection in storage.
[6] Showing scald and core breakdown.

TYPICAL FRUIT TEMPERATURES DURING TRANSIT WITHIN A CAR LOADED WITH PRECOOLED PEARS

The approximate boundaries of temperature zones in the load for the different days in transit as indicated in figure 4 were determined by direct computation on the basis of the difference in temperature and the distance between the points at which thermometer records were obtained. It will be noted that on the first day the temperatures were fairly uniform throughout the load a few hours after loading was completed. The succeeding diagrams show that the fruit temperatures gradually rose during the entire time in transit. From the beginning to the end of this time there was a noticeable increase in the fruit temperatures from day to day. The contrast between the temperatures on the first day and those on the eleventh day is striking because of the temperature increase throughout the load. During this period it appears that as the fruit warmed up, the progressively higher temperature zones that resulted had about the same boundaries.

As the load warmed up, the highest temperatures were found on the south side of the top layer in the quarter-length stack, and from this point they gradually spread over the top of the load. This is more

[6] HARTMAN, H. INVESTIGATIONS RELATING TO THE HANDLING OF ROGUE RIVER VALLEY PEARS ON EASTERN MARKETS. Oreg. State College, 27 pp. 1931. [Mimeographed.]
[7] See footnote 2.

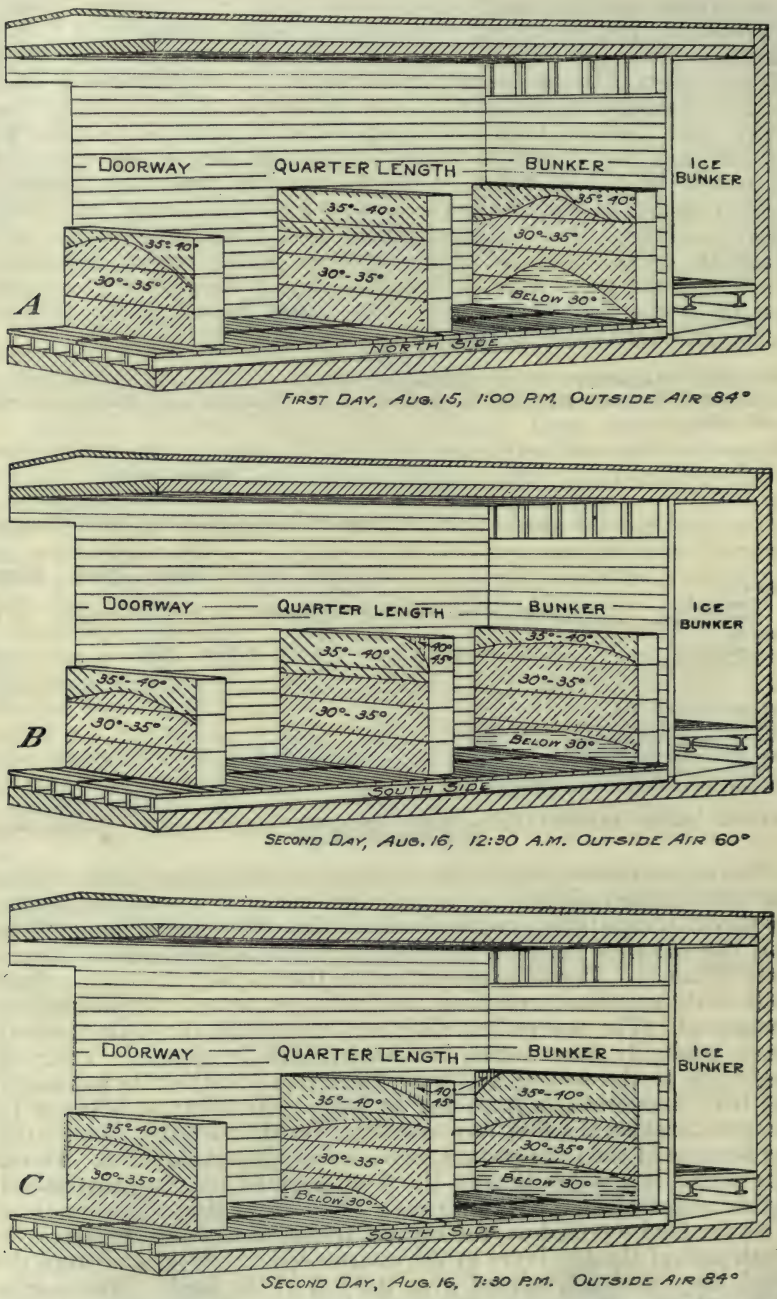
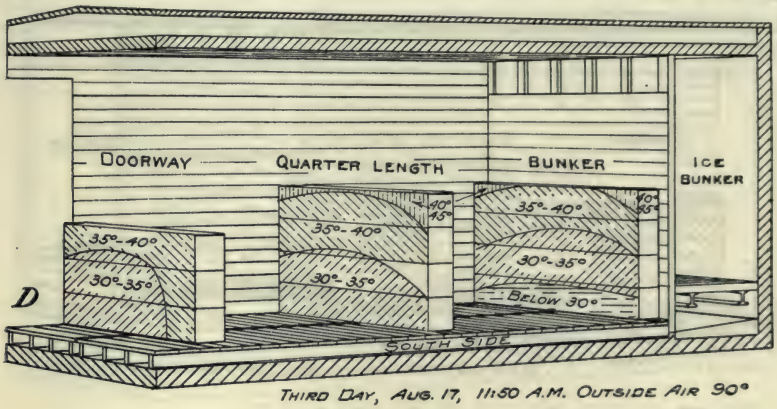
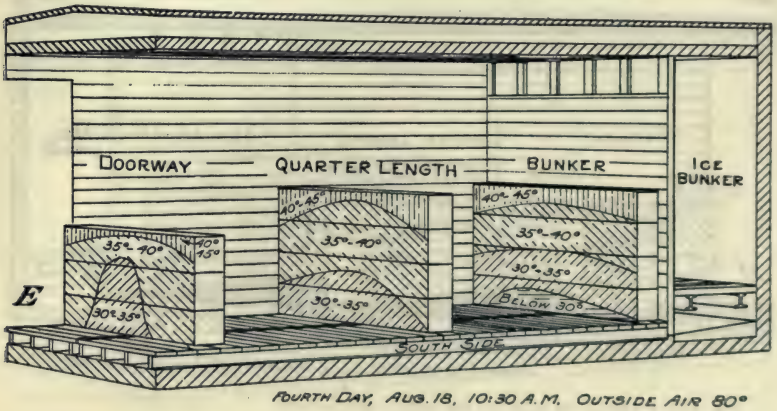


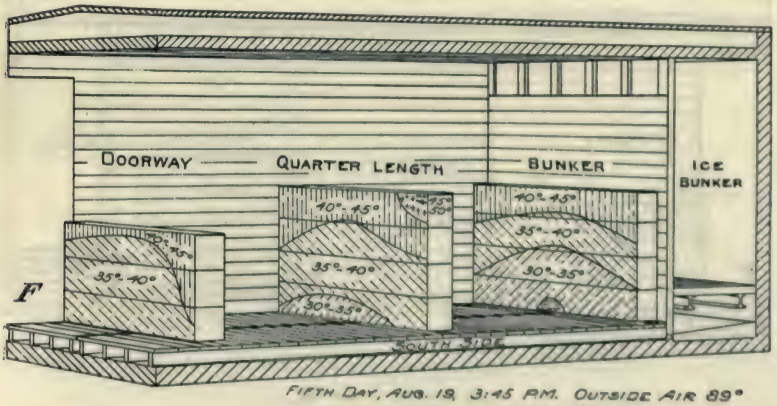
FIGURE 4.—Temperatures of a carload of pears in transit from Medford, Oreg., to Jersey City, N.J. (520 boxes; precooled; standard refrigeration; 3 percent salt). After the first day the position of the car on the tracks was reversed, when the north side of the car became the south side.



THIRD DAY, AUG. 17, 11:50 A.M. OUTSIDE AIR 90°

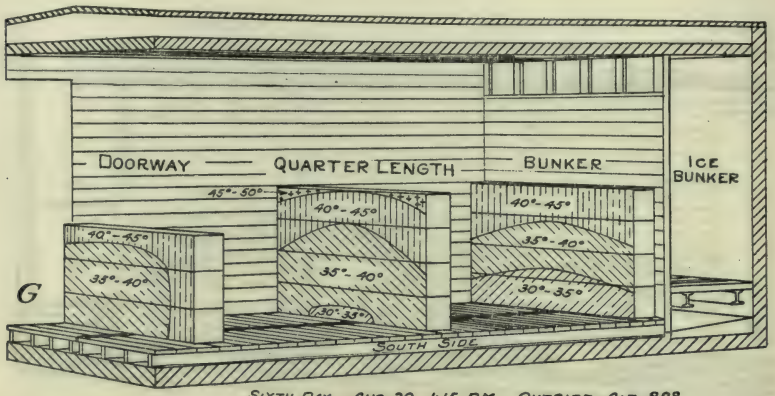


FOURTH DAY, AUG. 18, 10:30 A.M. OUTSIDE AIR 80°

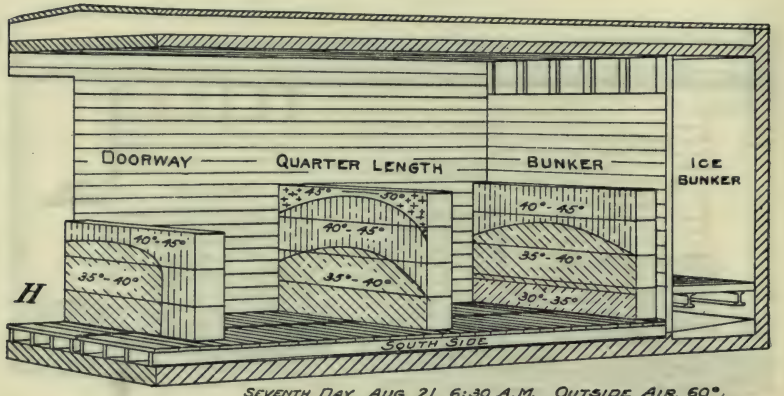


FIFTH DAY, AUG. 19, 3:45 P.M. OUTSIDE AIR 89°

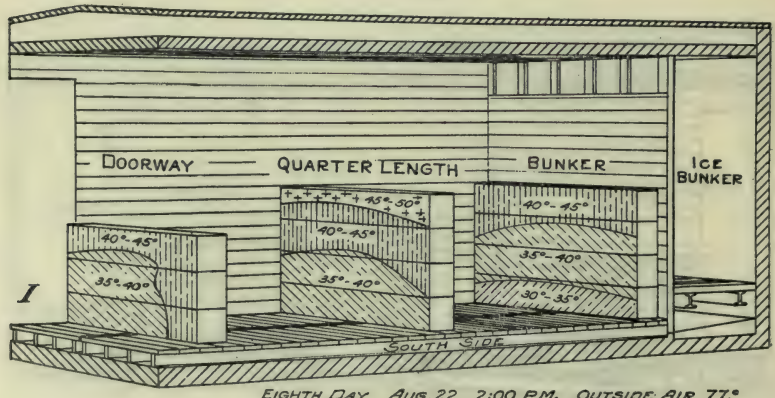
FIGURE 4.—Continued.



SIXTH DAY, AUG. 20, 1:15 P.M. OUTSIDE AIR 88°

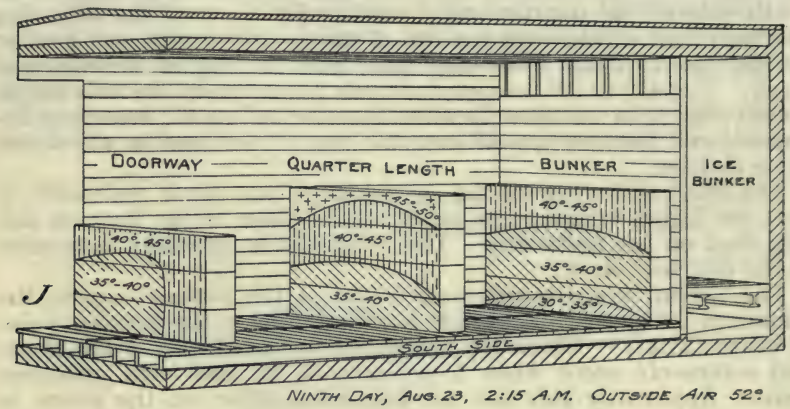


SEVENTH DAY, AUG. 21, 6:30 A.M. OUTSIDE AIR 60°.

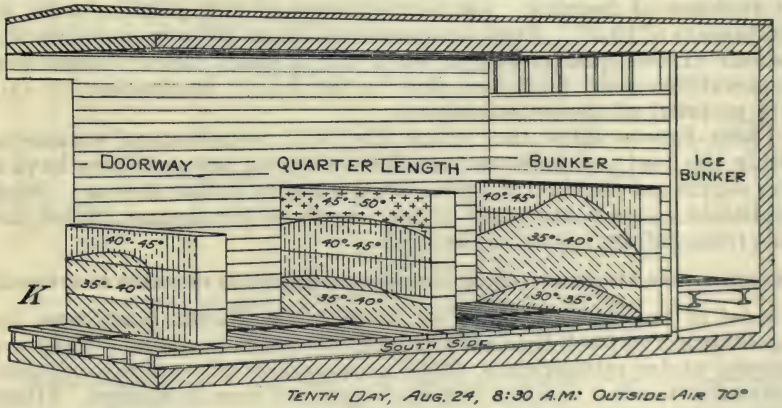


EIGHTH DAY, AUG. 22, 2:00 P.M. OUTSIDE AIR 77.°

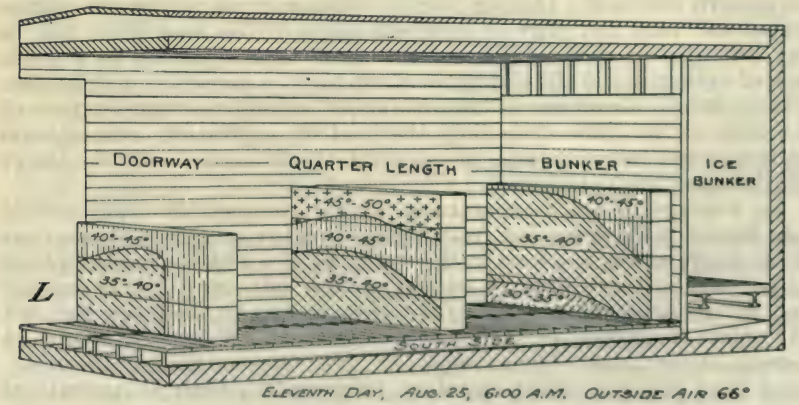
FIGURE 4.—Continued.



NINTH DAY, AUG. 23, 2:15 A.M. OUTSIDE AIR 52°



TENTH DAY, AUG. 24, 8:30 A.M. OUTSIDE AIR 70°



ELEVENTH DAY, AUG. 25, 6:00 A.M. OUTSIDE AIR 66°

FIGURE 4.—Continued.

clearly illustrated by following the 40° to 45° F. zone. These temperatures were first noticed on the second day at 12:30 a.m. on the south side of the quarter-length stack. By noon of the following day they had spread over the top of the quarter-length and bunker stacks, and 23 hours later they were over the top of the doorway stack. The 45° to 50° temperature zone appeared on the fifth day in transit (fig. 4) in the same location that the 40° to 45° zone first appeared, and likewise spread over the top of the load in about the same manner.

The effect of the sun on the south side of the car is noticeable in that the higher temperature zones extend closer to the floor on this side than on the north side. This condition is especially noticeable in the doorway stack.

The lowest temperatures were found at the bottom bunker, the minimum being 26.8° F., which is slightly below the freezing point of pears (28.4°).[8] These low temperatures lasted only a few hours and commonly occur when 3 percent salt is used with precooled pears. Apparently this had no deleterious effect on the pears, as an inspection at destination of fruit from the bottom bunker showed no evidence of freezing. Air temperatures at this position went to a minimum of 19.2°. Fruit temperatures below 30° were noted in the bottom of the quarter-length stack for a short time. These low temperatures were doubtless due to the heavy application of salt (318 pounds) at the initial salting.

These figures show that there are large temperature variations within the load and indicate that the outside air temperatures have a very significant effect on temperature conditions within the car. Such conditions cause a variation in the length of the storage life of the fruit from different parts of the load.

EFFECTS OF CAR TEMPERATURES IN TRANSIT ON BEHAVIOR OF PEARS IN STORAGE

Most of the Bartlett pears produced in the Pacific Northwest for consumption as fresh fruit are shipped to eastern markets. They are shipped under refrigeration either in nonprecooled carloads immediately after harvest or after varying lengths of time in storage. Many of these shipments are held in storage for varying periods after arrival on eastern markets. During transit, temperatures within the refrigerated car vary not only in different parts of the load from day to day but also in cars shipped at the same time resulting in a great lack of uniformity in the condition of the fruit on arrival at destination. This is due to a number of circumstances, chiefly the temperature of the fruit at the time of loading, the heat of respiration, atmospheric temperatures en route, and the amount of salt added with the ice at the different icing stations.

An average of the temperatures within comparable experimental cars loaded with precooled fruit during this investigation shows that the temperature of the fruit in the top layer of a 520-box load, shipped under standard refrigeration with 3 percent salt, ranged between 35° and 40° F. about 15 percent of the time in transit, between 40° and 45° about 60 percent of the time, and between 45° and 50° about 25 percent of the time. The average top-layer temperatures in the same-sized load shipped under standard refrigeration with 75 pounds of

[8] WRIGHT, R. C., and TAYLOR, G. F. THE FREEZING TEMPERATURES OF SOME FRUITS, VEGETABLES, AND CUT FLOWERS. U.S. Dept. Agr. Bull. 1133, 8 pp. 1923.

salt at each reicing were between 40° and 45° about three-fourths of the time in transit, and between 35° and 40° for the remainder of the time. The average temperatures of the fruit in the bottom layers of both cars were rather uniform, being between 30° and 35° about two-thirds of the time and between 35° and 40° for the remainder of the time in transit.

Temperature conditions in carloads of nonprecooled pears differ greatly from those in precooled loads. It was found that the average

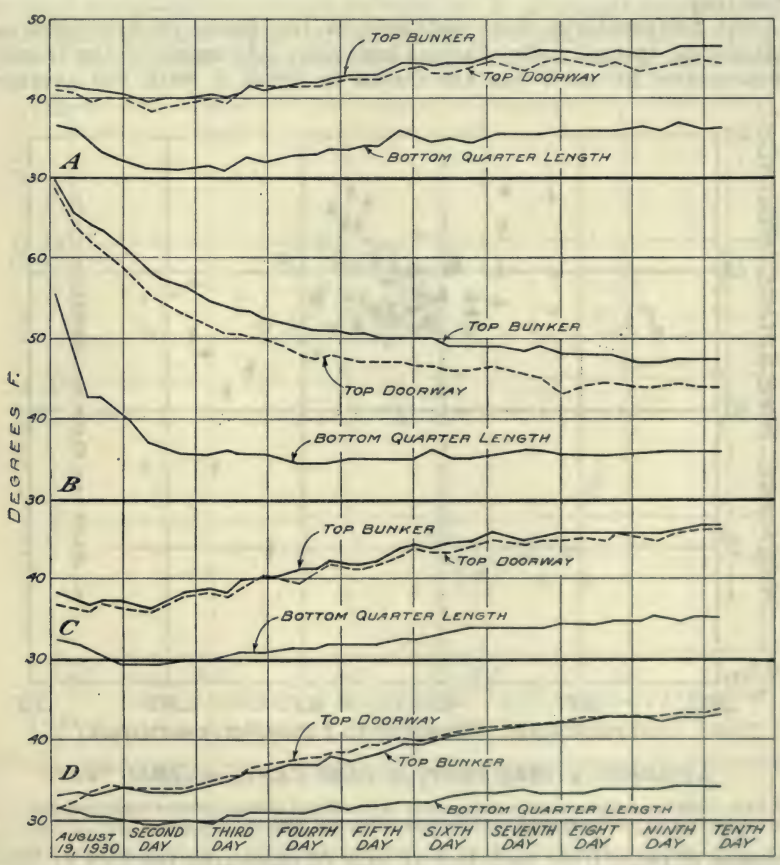


FIGURE 5.—Fruit temperatures in transit of carloads of Bartlett pears shipped during the 1930 test: *A*, 520-box load, precooled, standard refrigeration, 3 percent salt; *B*, 520-box load, nonprecooled, standard refrigeration, 5 percent salt; *C*, 720-box load, precooled, 3 percent salt; *D*, 744-box (through) load, precooled, standard refrigeration, 3 percent salt.

temperature in the top layer of nonprecooled loads shipped early in the season was between 45° and 50° F. about 72 percent of the time in transit, between 50° and 55° about 15 percent of the time, between 55° and 60° about 8 percent of the time, and above 60° about 5 percent of the time. The average of the bottom layer was between 35° and 40° about 86 percent of the time in transit, between 40° and 45° about 7 percent of the time, and above 45° the remainder of the time.

Temperature curves are shown in figure 5 to illustrate the temperature trend in the top and bottom layers of the various loads. It will

be noted that there was a gradual rise of temperatures in the precooled load and a gradual decline in the nonprecooled load, the temperatures in both loads being about the same during the last 3 or 4 days in transit. The significance of these temperature differences will be readily apparent by reference to table 7. A comparison of the rate of softening of the experimental fruit shipped in precooled and nonprecooled loads as given in table 7 indicates the importance of low fruit temperatures at time of shipment rather than at time of unloading.

Fruit temperatures were obtained in the boxes of experimental fruit during transit in the various test cars. Averages of the transit temperatures for each box are shown in figure 6, with the average

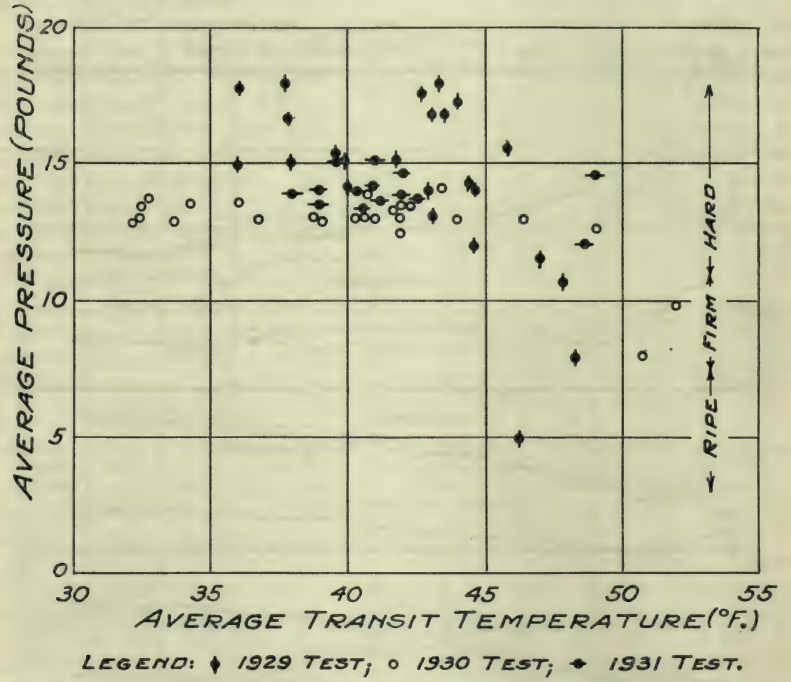


FIGURE 6.—Relation between average temperatures in transit and average pressure tests of experimental fruit on arrival in New York in the 1929, 1930, and 1931 tests.

firmness of pears from each box at time of unloading the cars in New York, for the three tests made in 1929, 1930, and 1931. It will be noted that the experimental fruit used in 1929 was firmer than that in the two following years, because the fruit shipped in 1929 was firmer at time of picking than in the succeeding years. The average pressure test of the experimental fruit on the day of loading was 16.6 pounds in 1929 and 14.2 pounds in 1930 and 1931.

These results show that the Bartlett pears in transit for 10 to 12 days at an average temperature below 46° F. were in a hard condition at the time of unloading. However, it was shown that Bartlett pears can be delivered in a firm condition and yet reach advanced

maturity before the end of their normal storage life because of the influence of warm temperatures to which they may have been subjected either in the orchard after picking or in transit, or a slow rate of precooling.

In figures 7 and 8 is summarized the behavior of the test fruit after different lengths of time in storage at 32° F. These data show that after approximately 30 days in cold storage at destination the pears that arrived in a firm condition had become ripe to eating ripe; those that were in a hard condition on arrival but were carried at an average temperature between 45° and 50° F. in transit had reached a firm condition, and those carried below an average of 45° were still hard. It is further apparent that pears transported at an average

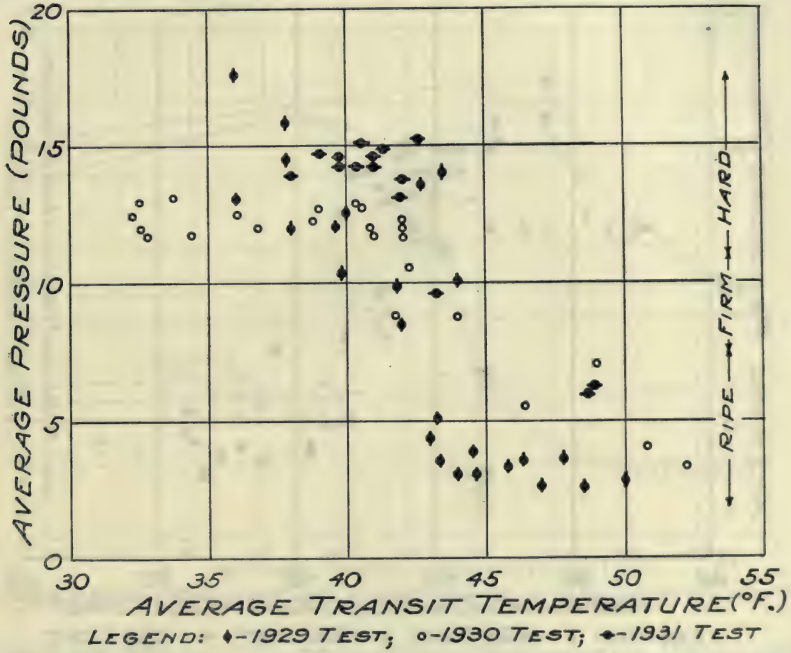


FIGURE 7.—Relation between average temperatures in transit and average pressure tests of experimental fruit after 30 to 36 days in 32° F. storage for the 1929, 1930, and 1931 tests.

temperature as high as 41° to 43° remained in good marketable condition at the end of a storage period of 50 to 60 days.

No ripening tests were made on the fruit used in the 1928 and 1929 experiments; that from the 1930 and 1931 tests was ripened at room temperatures. All lots ripened normally and with good quality except those shipped in the nonprecooled loads of the 1930 test. Magness, Diehl, and Allen [9] report similar results with California Bartletts picked in midseason. These pears were held at 43° for 12 days and then were placed in storage at 31° F. for 50 days. At the end of that time the fruit was removed from storage and held at 60°. It ripened

[9] See footnote 2.

in 5 days, and on the ninth day after removal from storage it was discarded as being overripe.

The average firmness of the experimental fruit used in the 1929, 1930, and 1931 tests, as shown in figures 6, 7, and 8, at time of unloading and after intervals in storage, is shown in figure 9. The curves in this figure indicating average maturity were obtained as mathematical averages of the pressure tests for each difference of 1° of the average temperatures in transit. It is apparent that the greatest change took place during the first 30 days in storage. The firmness of the fruit at the end of 53 to 60 days was very much the same as at the end of 30 days in storage. This indicates that precooled Bartlett pears may be transported at an average temperature as high

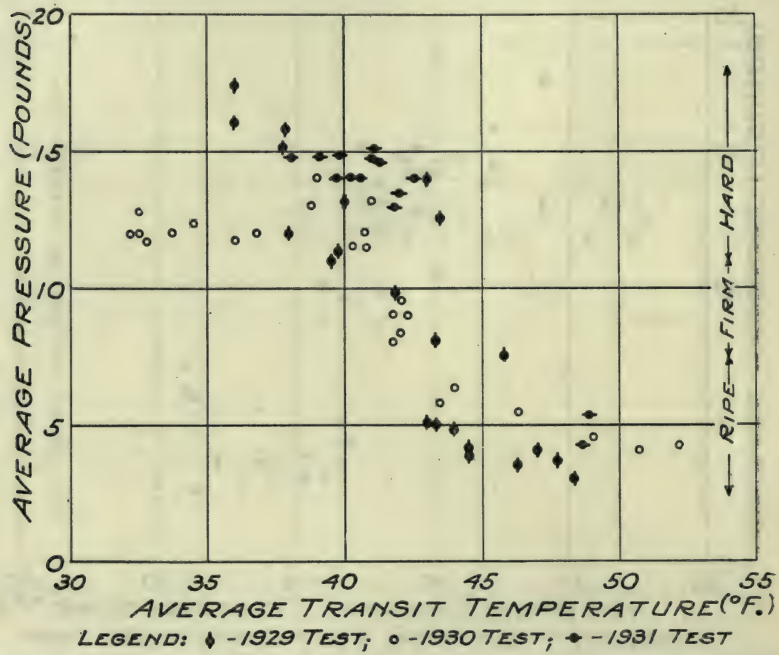


FIGURE 8.—Relation between average temperatures in transit and average pressure tests of experimental fruit after 52 to 64 days in 32° F. storage for the 1929, 1930, and 1931 tests.

as 41° to 43° F. during the 10- to 12-day transit period and still be in good marketable condition at the end of their normal storage life.

TEMPERATURES FOUND IN DIVIDED AND THROUGH LOADS

The divided load commonly used for both precooled and nonprecooled pears in the Pacific Northwest is one in which a space of varying width is left between the doors and braced with wooden timbers to prevent shifting and breakage of the boxes. It is also common practice, especially with nonprecooled pears, to leave a 6- to 12-inch air space between the rows. This method of loading obviously gives a clear channel for the passage of cold air from the bunkers and facilitates the removal of heat from the fruit.

In a load of precooled pears refrigeration is necessary primarily for the removal of heat that enters the car from the outside. With nonprecooled fruit, refrigeration is necessary not only to remove the heat which enters the car from the outside but also to remove the large amount of field heat in the fruit at the time of loading and the heat of respiration which it produces in transit. It appears, therefore, that although the divided and spaced load is probably the best method of loading for nonprecooled pears, a through load with a space between the load and side walls should be best for fruit that has been precooled because it provides a compact mass of cold material from which refrigeration is not as quickly lost.

The differences in temperature during transit of precooled fruit loaded in a through and in a divided, but not spaced, load were studied

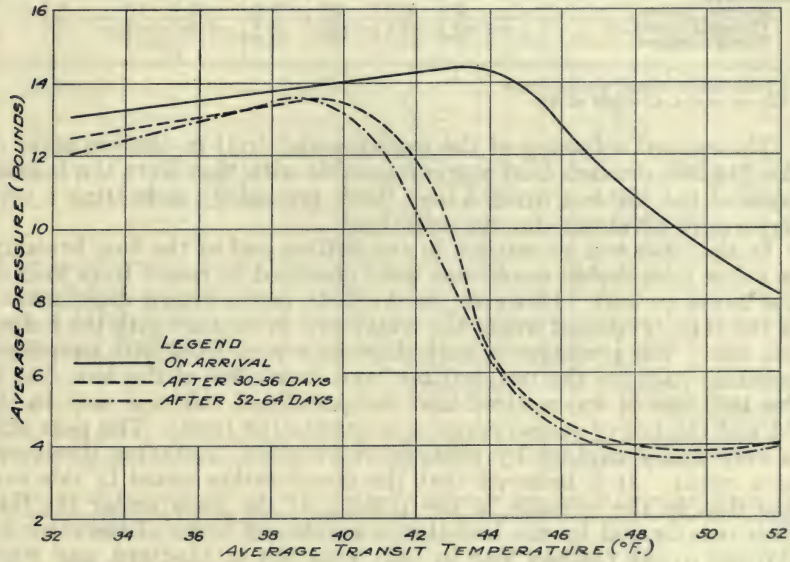


FIGURE 9.—Average firmness (3 years' tests) of experimental fruit on arrival at destination and after storage at 32° F. after being transported at various temperatures.

during the 1930 and 1931 transportation tests, using the 520-box and 720-box divided loads and the 640-box and 744-box through loads. The top-layer temperatures in the solid loads rose more slowly and did not reach the maximum temperatures shown in the divided loads. Results of the 1930 tests are shown in figure 5, *A*, *C*, *D*; those of the 1931 test are shown in table 8. As shown in figure 5, *D*, in a 744-box through load, the top-layer temperatures were below 40° F. for about half the time in transit and between 40° and 44° for the remainder of the trip. Those in the 720-box divided load (fig. 5, *C*) were between 35° and 40° about one-third of the time in transit, between 40° and 45° one-third of the time, and between 45° and 47° one-third of the time. The fruit for both these loads was comparable, having come from the same precooling plant, and was cooled to an average of 32° at the time of loading.

TABLE 8.—*Length of time, expressed in hours and in percentage of the transit period, during which the temperatures of precooled pears were within certain temperature ranges, in a test conducted in 1931*

Position of fruit and type of load	Time[1] in transit during which the temperatures of precooled fruit were within range of—							
	25°–30° F.		30°–35° F.		35°–40° F.		40°–45° F.	
	Hours	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*
Top layer:								
Divided, 720-box	0	0.0	0	0.0	50	20.0	200	80.0
Through [2], 744-box	0	.0	0	.0	94	37.6	156	62.4
Through, 640-box	0	.0	0	.0	64	25.6	186	74.4
Next-to-top layer:								
Divided, 720-box	0	.0	27	10.8	116	46.4	107	42.8
Through,[2] 744-box	0	.0	92	36.8	158	63.0	0	.0
Through, 640-box	0	.0	100	40.0	150	60.0	0	.0
Bottom layer:								
Divided, 720-box	50	20.0	189	75.6	11	4.4	0	.0
Through,[2] 744-box	54	21.6	196	78.4	0	.0	0	.0
Through, 640-box	45	18.0	205	82.0	0	.0	0	.0

[1] Total time in transit was 250 hours.
[2] Boxes on end; all others on side.

The rate of softening of the experimental fruit in the top layer of the 744-box through load was comparable with that from the bottom layer of the 520-box divided load (both precooled), indicating a very important advantage for the solid load.

In the 1930 test no settling in the bottom end of the box, bruising, or other undesirable conditions were observed to result from loading the boxes on end. However, in the 1931 test a brown discoloration of the skin developed where the fruit came in contact with the bulged box lids. The packages in both shipments were lined with paraffined toweling pads on the top, bottom, and four sides of the box, but in the 1931 test it was noticed that the paraffined side was next to the lid and the heavy coarse paper was next to the fruit. The pear skin is very easily bruised by rubbing or abrasion, becoming discolored as a result. It is believed that the discoloration noted in this case was due to the mistake in the placing of the pads under the lids. This is indicated by the fact that a number of boxes of the same lot shipped in the 744-box load in 1931 were left at Medford, and when the fruit ripened no discoloration was found. The discoloration was doubtless caused by the vibration or shaking of the car en route and the consequent rubbing of the pears against the wrong side of the pad.

The advantages of the through load for precooled fruit were also shown by the lower temperatures obtained in the 640-box through load, where the boxes were loaded on their sides in the usual manner. Another advantage of the through load for precooled pears is that it saves the expense of bracing necessary with the divided load. The breakage of boxes shipped in the test cars was small. However, observations made on these cars and as many other cars as possible indicated that the greatest amount of breakage occurred in the 511[10]- or 520-box loads, and generally at the doorway. Breakage was more noticeable when the rows were spaced. The least breakage was noted in the through and 720-box loads.

[10] Load commonly used in the State of Washington.

PRECOOLING REFRIGERATOR CARS

Prior to 1929, in the Medford district the initial salting generally took place at the time the cars were preiced. To some extent this practice is still followed in the other districts of the Pacific Northwest. The object of this procedure is to precool the interior of the car and have maximum refrigeration for the pears as soon as loading is completed.

Since loading and bracing the load may require several hours, during which time the doors are open, there is a steady loss of cold air from the bottom doorway and an inflow of warm air at the top. This warms the car, causes heavy ice meltage, and results in a wastage of both salt and ice. Consequently, much of the benefit of the salting of the

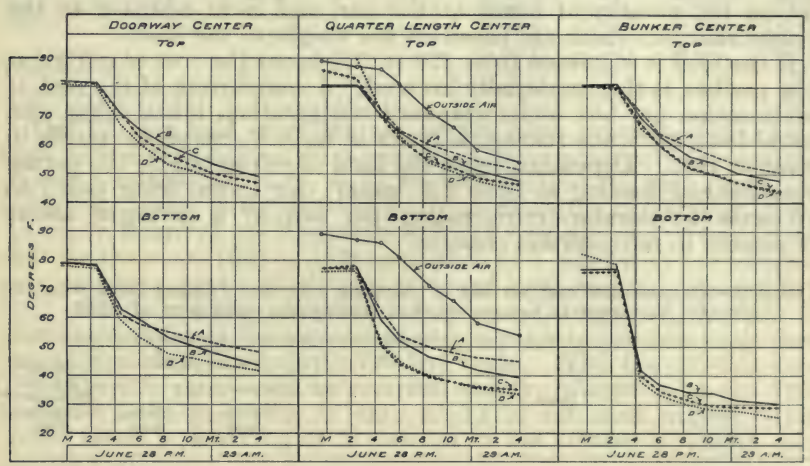


FIGURE 10.—Air temperature in various parts of empty refrigerator cars, with 11,000 pounds of ice in the bunkers of each car, at Yakima, Wash., June 28–29, 1929. Car *A* received no salt; car *B* received 1 percent, car *C*, 2 percent, and car *D*, 3 percent salt at time of initial icing.

initial ice is lost, in proportion to the length of time the doors are open.

If the car is iced far enough ahead of loading to cool it without the aid of salt there should be less loss of refrigeration. A test was made with four cars to determine the effects on the cooling of empty refrigerator cars when 1, 2, and 3 percent salt and no salt were used, with bunkers filled to capacity with ice. This test was made in Yakima on June 28 and 29, 1929. Temperatures of the air were obtained near the ceiling and floor along the center line and near the side wall of each car. Little difference in the temperature was found between the center and side positions. Temperatures along the center line of the car are shown in figure 10.

The use of salt gave lower temperatures and faster cooling in the empty refrigerator car. The use of ice alone cooled the air near the ceiling from 83° to about 50° F. in 12 to 14 hours, whereas the same

result was accomplished in 4 to 5 hours by the use of salt. It is evident, therefore, that icing the car 10 to 12 hours prior to loading should satisfactorily cool it without the necessity of using salt. The most satisfactory and economical refrigeration of the lading can therefore be secured by delaying the initial salting until after loading has been completed.

ECONOMIC ADVANTAGES OF HEAVIER LOADING OF PRECOOLED PEARS

The heavier loading of precooled pears has brought economic savings. Some of these savings are too involved to estimate, but certain others which can be determined are briefly discussed below.

The charge for refrigeration is based on a fixed amount per car, not on the number of boxes in the car, and is in addition to the freight charges, which are based on the weight of the load.

If the load is increased from 520 to 720 boxes the cost of refrigeration per box is thus materially lowered. A comparison of the cost of refrigeration per box under standard refrigeration, initial icing, and initial icing with one reicing, is given in table 9, based on tariffs in effect in 1933. Depending upon the kind of refrigeration, the saving from heavier loading is from 2.4 cents (for initial icing only) to 5.6 cents (for standard refrigeration) per box, or a saving of about 28 percent in refrigeration charges.

TABLE 9.—*Comparative cost per box of shipping 520- and 720-box loads from the Pacific Northwest to eastern markets during the early part of 1933*

Item	Cost per box		Saving per box from use of heavier load
	720-box load	520-box load	
	Cents	*Cents*	*Cents*
Standard refrigeration ($105 per car)	14.58	20.19	5.61
Initial ice	6.22	8.62	2.40
Initial ice and one reicing	9.30	12.88	3.58
Freight at $1.55 per hundred pounds [1]	79.05		
Freight at $1.73 per hundred pounds		88.23	9.18

[1] This rate applies only to a 36,000-pound minimum load (720 boxes).

The freight rate for pears prior to 1933 was $1.73 per 100 pounds for a 26,000-pound minimum load. Early in 1933 a new rate of $1.55 was granted for a 36,000-pound (720-box) minimum load of pears, or a saving of 9.18 cents per box. This gives a total saving to the shipper of 11.6 to 14.8 cents per box, depending upon the type of transit refrigeration. Since the cost of precooling is from 10 to 15 cents per box, the saving in refrigeration and freight charges more than offsets the cost of precooling, which is essential to the use of this method of shipment. Aside from the considerations just mentioned, the cost of precooling has generally been considered a good investment because of the improved carrying and storage qualities of the fruit.

Precooling of pears has resulted in a saving, due to the fact that less ice is required in transit. The average difference in ice meltage by shipments of precooled and nonprecooled pears under standard refrigeration is shown in table 10 to be about 6,000 pounds during the time these tests were made, or a saving of 23 percent in favor of the

precooled load. As shown in table 5, the differences in ice meltage between shipments of precooled pears in 520-box and 720-box loads are negligible.

TABLE 10.—*Total and average quantities of ice placed in bunkers and melted in cars containing 520-box loads of precooled pears receiving 3 percent salt and nonprecooled pears receiving 5 percent salt*

Year of test	Precooled pears		Nonprecooled pears	
	Ice in bunkers	Ice melted	Ice in bunkers	Ice melted
	Pounds	*Pounds*	*Pounds*	*Pounds*
1929	20,790	13,574	26,388	18,668
1930	19,701	10,291	26,269	17,318
1931	19,425	10,544	25,359	16,478
Average	19,972	11,470	26,005	17,488
Percent melted		57.4		67.2

The 720-box load gives the carrier the same revenue-paying tonnage with a reduction of 28.5 percent in the amount of nonrevenue-paying tonnage necessary to be hauled; that is, the tare weight of refrigerator cars. According to a study made by the Pacific Northwest Advisory Board of the American Railway Association [11] it was found that for the years 1928 to 1931, inclusive, 77.7 percent of the refrigerator cars sent east loaded were returned west empty. The empty haul west is entirely nonrevenue paying. It requires 100 cars to haul approximately the same quantity of pears in 520-box loads that can be hauled in 72 cars with 720-box loads. With the 520-box load 78 of the 100 cars would be returned empty, whereas with the 720-box load only 56 of the 72 cars would be returned empty. This would result in a saving of 28 percent in the number of empty cars hauled west.

The freight cost, as shown in table 9, is 88.2 cents per box when the rate is $1.73 per hundredweight. An increase in the load from 520 to 720 boxes increases the revenue per car by $176.46. Likewise, when the rate is $1.73 per hundredweight for the 520-box load and $1.55 for the 720-box load, the revenue, due to the heavier load, is increased $110.36 per car. Savings in rolling stock, switching, maintenance, and office work, on account of the heavier load, are also material, but no attempt is made here to estimate the amount.

DISCUSSION

These investigations have shown that the precooling of pears prior to loading in refrigerator cars make certain changes desirable in the manner of handling and refrigerating the fruit during the transportation period. The removal of field heat eliminates many of the difficulties encountered in the transportation of warm pears to market. The methods necessarily employed with warm fruit are neither economical nor entirely applicable to precooled shipments.

It was found that if the fruit is precooled, the number of boxes of pears which can be loaded in a car can be increased from 511 or 520 to 720 without increasing transit temperatures or the rate of ripening.

[11] ARNETT, H. J. REPORT OF PACIFIC NORTHWEST ADVISORY BOARD, AMERICAN RAILWAY ASSOCIATION, 2D QUARTER. P. 2. 1932.

Since these tests were conducted with the Bartlett variety during periods of high atmospheric temperatures, it is believed that similar results would be obtainable with later varieties, which doubtless would be shipped under more favorable weather conditions.

With nonprecooled shipments it was found that satisfactory results were secured from use of the present method of adding salt, i. e., the amount of salt added being a percentage of the ice supplied. This provides the coldest temperature at the beginning of the trip, when it is needed most. However, for precooled shipments, refrigeration is needed only to counterbalance the heat that enters through the walls of the car and the small amount given off through respiration. Consequently, a large amount of refrigeration at the beginning of the transit period, such as that secured when the salt is added on the percentage basis, is not necessary. It would be preferable to add the salt so as to afford uniform refrigeration during the entire transit period, or to secure more refrigeration at the end of the trip when fruit temperatures would otherwise be the highest.

The application of 75 pounds of salt at each reicing station with shipments of precooled fruit, rather than 3 percent salt, produced more constant and lower temperatures in all the layers, especially at the end of the transit period, and insured a longer storage life for the fruit after arrival at destination. As these studies were made when atmospheric temperatures were high, the quantity of salt to be used at each reicing should be reduced during cooler weather.

It is evident that while Bartlett pears are in transit they require the maximum refrigeration that can be furnished without freezing the fruit. Shipments under standard refrigeration without salt or under initial icing with two reicings en route did not arrive at destination with the top layer in a satisfactory condition for either storage or immediate sale with the high atmospheric temperatures prevailing during these tests.

SUMMARY

The transportation of pears from the Pacific Northwest to eastern markets was studied during the period from 1928 to 1931, inclusive. The investigations were made primarily to determine (1) the feasibility of increasing the size of the load when precooled pears are shipped, (2) the effect of different methods of loading, and (3) the most efficient method of applying salt for refrigeration during transit.

It was found that precooled pears shipped in 720-box loads arrived at the market in a firm condition and were as suitable for storage as those shipped in 520-box loads. The pears were shipped in cars taken from those that were being used for shipping pears and were from 5 to 8 years old. In all of the tests the fruit was handled throughout according to the usual commercial practice, both at shipping point and at destination.

In precooled shipments the placing of 75 or 50 pounds of salt on the ice at each icing station produced lower and more uniform temperatures and was more effective in retarding ripening than the application of 3 percent salt.

The initial salting was more effective and economical in producing low fruit temperatures when applied after rather than before loading.

Lower temperatures were obtained in precooled shipments when the boxes were loaded close together and an air space was left between the load and the side of the car.

The transit temperatures of precooled pears shipped in the through load were lower and the subsequent storage life was longer than when the pears were shipped in the divided load.

Bartlett pears from the Pacific Northwest when picked at the proper stage of maturity can be shipped at an average temperature as high as 41° to 43° F. for the 10 or 12 days necessary to reach eastern markets and subsequently remain in good marketable condition after 2 months' storage at 32°. They can be transported at an average temperature as high as 50° if intended for immediate consumption. Average transit temperatures higher than 50° are not desirable.

The heavier loading of precooled pears gives a material economic saving to both the shippers and the carriers.

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PHYSIOLOGIC SPECIALIZATION IN PUCCINIA CORONATA AVENAE[1]

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The Bureau of Plant Industry in cooperation with the Iowa Agricultural Experiment Station

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INTRODUCTION

The existence of physiologic forms of *Puccinia coronata avenae* (Corda) Eriks. and Henn., as in other of the cereal rusts, has been reported by Hoerner (*18*),[3] Popp (*30*), Parson (*28*), Murphy (*24*), Frenzel (*15*), and Peturson (*29*). In this bulletin are presented (1) a standardized numerical designation for the physiologic forms of *P. coronata avenae* reported to date in North America; (2) something of the nature of these forms and their relationship to their gramineous and alternate hosts; (3) data showing the prevalence and geographic distribution of the forms in the years from 1927 to 1932, inclusive; (4) the reaction of oat varieties to natural and artificial inoculation; and (5) the gramineous-host range of six forms.

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[2] The writer expresses his appreciation to the following, all of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U.S. Department of Agriculture: H. B. Humphrey, principal pathologist, under whose direction these investigations were conducted; T. R. Stanton, senior agronomist, for furnishing seed of the new and foreign varieties studied; and M. N. Levine, pathologist, for invaluable assistance in the preparation of the manuscript; also to B. Peturson, assistant pathologist, of the Dominion Rust Research Laboratory, Winnipeg, Canada, for furnishing data and assistance necessary for the adoption of a standardized numerical designation for the physiologic forms of crown rust; I. E. Melhus, head of the department of botany and plant pathology, and S. M. Dietz, associate professor of botany, both of the Iowa State College, for assistance and helpful suggestions; and to many who kindly sent collections of rust from the United States, Canada, and Mexico.

[3] Italic numbers in parentheses refer to Literature Cited, p.47.

HISTORY

Hoerner (*18*) first reported the presence of physiologic specialization within *Puccinia coronata avenae*. He distinguished four physiologic forms on the basis of the reaction of two oat varieties, Ruakura ((Iowa no. 73) C.I.[4] 2025), and Green Russian ((Iowa no. 96) C.I. 2890), as follows: Form 1, infects both varieties normally; form 2, infects both varieties weakly; form 3, infects Ruakura weakly and Green Russian normally; and form 4, infects Ruakura normally and Green Russian weakly.

Popp (*30*) identified 22 cultures of *P. coronata avenae* collected from five Provinces of Canada. Using Green Russian, Sterisel ((Sterilis selection) C.I. 2891), and White Russian (Minn. no. 539) as differential oat varieties, he distinguished four physiologic forms as follows: Form 1, infects Sterisel weakly, White Russian normally, and Green Russian normally; form 2, infects all three varieties weakly; form 3, infects Sterisel normally, White Russian weakly, and Green Russian weakly; and form 4, infects all varieties more or less normally.

Parson (*28*) obtained 15 collections of *P. coronata avenae* from the United States and Canada. Using four oat varieties as differential hosts, he distinguished five physiologic forms:

Ruakura (C.I. 2025) resistant:
- *Avena sterilis nigra* resistant ..... form 3
- *Avena sterilis nigra* susceptible:
  - Red Rustproof (C.I. 1815) resistant ..... form 5
  - Red Rustproof (C.I. 1815) susceptible ..... form 4

Ruakura (C.I. 2025) susceptible:
- Green Mountain (C.I. 1892) resistant ..... form 2
- Green Mountain (C.I. 1892) susceptible ..... form 1

Parson determined the reaction of 27 varieties, selections, and species of oats to each of his forms and found none resistant to more than three of them. He noted that certain forms tended to produce teliospores soon after urediospores appeared, whereas other forms produced teliospores much later or not at all. He found no correlation between resistance and early teliospore formation.

The writer (*24*) obtained 45 collections of *Puccinia coronata avenae*, of which 32 were from *Avena* and 13 from *Rhamnus*. An equal number of cultures isolated from these collections were tested individually on pure-line selections of 33 varieties and species of oats. Eight of these, acting as differential hosts, disclosed the following nine physiologic forms:

Belar (C.I. 2760) resistant:
- Red Rustproof (C.I. 1079) resistant:
  - College Algerians (C.I. 2052) resistant ..... form 3
  - College Algerians (C.I. 2052) susceptible ..... form 8
- Red Rustproof (C.I. 1079) susceptible:
  - Cowra (C.I. 2761) resistant ..... form 9
  - Cowra (C.I. 2761) susceptible ..... form 7

Belar (C.I. 2760) susceptible:
- Iowa no. 69 (C.I. 2463) resistant:
  - *Avena strigosa* (C.I. 1782) resistant:
    - Anthony (C.I. 2143) resistant ..... form 4
    - Anthony (C.I. 2143) susceptible ..... form 2
  - *Avena strigosa* (C.I. 1782) susceptible ..... form 1
- Iowa no. 69 (C.I. 2463) susceptible:
  - Hawkeye ((Iowa no. 102) C.I. 2464) resistant ..... form 6
  - Hawkeye ((Iowa no. 102) C.I. 2464) susceptible ..... form 5

[4] C.I. indicates accession number of the Division of Cereal Crops and Diseases.

The 13 aecial collections from five species of *Rhamnus* were identified as follows: Four from *R. cathartica* L. were form 3; six from *R. lanceolata* Pursh., were form 5; one each from *R. tinctoria* Waldst. and Kit., *R. montana* Rosten., and *R. infectoria* L. were forms 7, 8, and 9, respectively.

Peturson (*29*) studied the effect of temperature on host reactions to physiologic forms of *Puccinia coronata avenae*. The effect of temperature on the development of four physiologic forms on six differential host varieties was determined. Green Mountain (C.I. 1892), White Tartar (C.I. 551), and Green Russian were resistant to his form 7 at a constant temperature of 57° and 70° F. and susceptible at 77° F., whereas Red Rustproof (C.I. 1039), Sterisel (Sterilis selection), and Ruakura were uniformly susceptible at these temperatures. The reactions of the same varieties to Peturson's forms 1, 3, and 4 were not affected by changes in temperature, except that Red Rustproof was resistant to form 4 at 57° F. and susceptible at 70° and 77° F. Peturson emphasizes the importance of maintaining a uniform temperature while identifying forms of *P. coronata avenae*.

Frenzel (*15*) studied 55 cultures of *Puccinia coronata avenae* (*P. coronifera* f. sp. *avenae* Kleb.) isolated from 27 collections collected throughout Germany in 1928 and 1929. He isolated 33 physiologic forms among these collections by the differential reaction of nine oat varieties. Four of these, Ruakura, Red Rustproof (C.I. 1815), Green Mountain, and *Avena sterilis* var. *nigra* (C.I. 840–49) had previously been used by American investigators as differential hosts. Frenzel considered a difference of 0-type reaction contrasted with a 1-type as sufficient to differentiate physiologic forms. He observed a heterogeneous or X-type reaction on Green Mountain and *A. sterilis* var. *nigra* to certain forms. Single-spore isolation from the resistant-type and susceptible-type pustules within those heterogeneous types failed to segregate forms that would produce homogeneous types on the particular variety involved. There was no apparent regularity in the geographic distribution of the 33 forms. Only 2 of the 20 isolated from the 1928 collections were reisolated from those collected in 1929.

Frenzel observed a marked difference in the rapidity of teliospore formation on certain varieties with certain physiologic forms. He considered this difference sufficiently important to warrant its possible use in differentiating physiologic forms. He determined the reaction of 198 varieties of oats to 8 of his forms and found that, with few exceptions, all were completely susceptible. He also determined the reaction of 19 species of grasses to 13 forms and found very slight evidence of physiologic specialization in relation to the species tested.

MATERIALS AND METHODS

Leaves infected with *Puccinia coronata avenae* were collected from naturally inoculated oat plants and from *Rhamnus* naturally and artificially inoculated in 1927 to 1932, inclusive. Because of their short germination period, aecial collections were immediately transferred to oat plants and the resulting uredial stage was continued, or the infected leaves were stored in the refrigerator. All cultures were maintained on the variety Iomine (C.I. 2827) in 1927 and 1928. This variety, however, showed some resistance to certain forms, and

Markton (C.I. 2053) was substituted for it in 1929, 1930, 1931, and 1932.

Single-uredium cultures were isolated by inoculating Markton or Iomine plants sparsely with spores from a particular collection. About 6 or 7 days after inoculation, before any uredia had opened, a plant bearing a single uredium was selected. It was then placed under a covered lamp chimney and the urediospores were allowed to mature. Because of the possibility of the presence of more than one physiologic form in a collection, two single-uredial isolations were usually made from each collection. Each culture sprang originally from a single uredium.

Seedling plants usually were inoculated between 4 and 6 p.m. The first leaf of each was drawn gently between the moistened forefinger and thumb; then the entire plant was moistened with a constant-pressure sprayer. The plants were then moved to the stock-culture room where each plant was inoculated with the desired culture by applying with a flat needle a small amount of crown-rust urediospores to the moistened surface of the first leaf. The plants were again sprayed, placed in a moist chamber, and kept there about 14 hours. In order that the plants might not dry too quickly or otherwise become injured, the chambers were opened at about 8 a.m. and the plant retained in the open chamber until about 4 p.m.

Where infection types were to be determined, the plants were placed in muslin compartments like those described by Melhus, Dietz, and Willey (*23*), and those used for stock cultures were held under lamp chimneys. The tops of the chimneys were covered with a thin layer of cotton held between two pieces of cheesecloth, and this was fastened with a rubber band. Each lamp chimney would cover the contents of a 3-inch flowerpot. The pots were supplied with water by subirrigation.

Glass chambers lined with muslin and packed with sphagnum moss and tanks made of sheet metal with a false bottom and glass top were satisfactory moist chambers.

Special precautions were taken throughout these investigations to prevent contamination. All plants were sown, grown, and prepared for inoculating in a separate greenhouse where there were no infected plants. By spraying the walls, roof, and hot steam pipes of the room used for inoculating with a fine spray of water just before inoculation, it was found, by use of check plants, that contaminating spores were effectively removed from the air. This humid atmosphere also seemed to inhibit the spread of spores while inoculation was in progress. Before preparing plants for inoculation and with each change in culture, the hands and arms were thoroughly washed with soap and water. The flat needle used for applying the urediospores was sterilized by heating.

SELECTION OF DIFFERENTIAL OAT VARIETIES

It is obviously desirable that all investigators of physiologic specialization in crown rust should use a uniform method of numbering the physiologic forms identified. This necessitates the adoption of a uniform and standard set of differential hosts.

In order to give a standard designation to each physiologic form reported to date in North America, it was necessary to include in the standard set of differential hosts certain of the differential varieties used by earlier investigators. After considerable preliminary work,

during which approximately 300 varieties were inoculated with 10 different cultures (representing 6 physiologic forms) of crown rust, 33 potential differential hosts were selected. These 33 varieties were inoculated with a total of 245 different cultures, representing 13 physiologic forms. The number of differentials employed in identifying forms was then reduced to the minimum. Thus, 11 varieties were selected as standard differential hosts for the identification of physiologic forms of *Puccinia coronata avenae*. The name, C.I. no., and previous designation of each variety, and the names of the investigators who have previously used these varieties as differential hosts for identifying physiologic forms of crown rust are presented in table 1.

TABLE 1.—*Standard differential oat varieties used to identify physiologic forms of Puccinia coronata avenae*

Variety	C.I. no.	Previous designation	Investigators
Ruakura [1]	2025	Iowa no. 73	Hoerner (*18*), Parson (*28*), Peturson (*29*), Frenzel (*15*).
Green Russian [2]	2890	Iowa no. 96	Hoerner (*18*), Popp (*30*), Peturson (*29*).
Hawkeye	2464	Iowa no. 102	Murphy (*24*).
Anthony	2143	----	Do.
Sunrise	982	----	Not previously reported.
Green Mountain	1892	----	Parson (*28*), Peturson (*29*), Frenzel (*15*).
White Tartar	551	----	Peturson (*29*).
Red Rustproof	1815	----	Parson (*28*), Peturson (*29*), Frenzel (*15*).
Sterisel	2891	Sterilis selection	Popp (*30*), Parson (*28*), Peturson (*29*).
Belar	2760	----	Murphy (*24*).
Glabrota	2630	----	Not previously reported.

[1] The Ruakura Rustproof variety used by Popp (*30*) may have been Ruakura (C.I. 2025). Ruakura Rustproof was not tested by the writer.

[2] B. Peturson, of the Dominion Rust Research Laboratory, Winnipeg, Canada, informed the writer in a letter dated Aug. 25, 1931, that the Green Russian used by Parson (*28*) did not react to certain of his physiologic forms as did Green Russian ((Iowa no. 96) C.I. 2890). The writer was unable to obtain seed of the Green Russian used by Parson.

Prior to the adoption of these 11 standard differential hosts all cultures were identified by the differential reaction of 33 oat varieties, within which group were included the 8 reported as differentials by the writer (*24*), and all except Sterisel and Glabrota of the standard differential varieties mentioned. Seed of these 33 varieties was obtained from S. M. Dietz and L. C. Burnett, of the Iowa Agricultural Experiment Station, and from T. R. Stanton, of the Division of Cereal Crops and Diseases, Bureau of Plant Industry. In April 1930 seed of Ruakura, Green Russian, Sterisel, Green Mountain, Red Rustproof (C.I. 1815), and White Tartar was received from B. Peturson, of the Dominion Rust Research Laboratory. This seed was of the same origin as that used by Hoerner (*18*), Popp (*30*), Parson (*28*), and Peturson (*29*). Because of its origin, the seed of the varieties obtained from Peturson was used as the source for the corresponding standard differential hosts. The reaction to physiologic forms 1 to 8, inclusive, and 10, 13, and 20 to 28, inclusive, of each of the varieties secured from Peturson and of the corresponding varieties already in use was determined and found to be similar.

Ten or more seedlings of each differential variety were inoculated in the first-leaf stage with each culture of crown rust studied. The first 7 of the 11 standard differential hosts gave a heterozygous reaction to one or more cultures of crown rust. When a variety appeared heterozygous for reaction to a particular culture a larger number of

plants was inoculated and the predominating reaction was recorded. Continuous selection of seed from these predominating types has apparently purified each variety to the extent that heterozygosity is of little concern. Pure-line selections from each variety have been tested with all forms except 10, 17, and 18. These strains are now being increased as a source for homozygous standard differential varieties [5] for the identification of physiologic forms of crown rust.

INFECTION TYPES OF CROWN RUST

In recording the reaction of different oat varieties to crown rust, it was necessary to adopt a series of rust manifestations which would describe the classes of host reactions observed. The infection types of crown rust observed were similar to those described by Stakman, Levine, and Bailey (*32*) for *Puccinia graminis avenae* Eriks. and Henn. and are here described as follows:

Host reaction	*Symbol and infection type*
Immune	I, No macroscopic evidence of infection.
Nearly immune	0, No uredia formed; necrotic areas or chlorotic flecks present.
Highly resistant	1, Uredia few, small, always in necrotic areas; also more or less necrotic areas produced without the development of uredia.
Moderately resistant	2, Uredia fairly abundant, small to midsized, always in necrotic or very chlorotic areas; necrotic areas seldom without uredia.
Mesothetic	M, Apparently a combination of two or more extreme types in varying proportions.
Moderately susceptible	3, Uredia abundant, midsized, and surrounded by chlorotic areas; necrotic areas entirely absent.
Completely susceptible	4, Uredia abundant, large; no necrosis or chlorosis immediately surrounding the uredia.

The reaction of all plants to crown rust was recorded on the tenth day following inoculation and checked on the fourteenth day. From date of inoculation to that of recording, the plants were kept at approximately 70° F. and ordinarily within the range of 65° to 75°, and with light and moisture conditions as near as practicable to the optimum for growth of the oat plants.

The infection type of crown rust on a specific pure line of oats inoculated with a specific physiologic form apparently would be very constant if temperature, light, atmospheric humidity, soil moisture, and nutrition were uniform and constant. Under the conditions of this investigation these factors could be only partly controlled. Physiologic forms were not identified in the summer or whenever the

[5] Morphologial descriptions of the strains selected as standard differential hosts are not presented because different strains of a particular variety may be morphologically identical but react differently to one or more of the physiologic forms described. The varieties, with the exception of Hawkeye and Anthony, to which the strains selected as standard differential hosts belong have been described elsewhere. Archer (*2*) describes Ruakura; Etheridge (*13*), Green Russian, Green Mountain, White Tartar, Red Rustproof, and Sterilis selection (very similar to Sterisel); Callaghan (*4*), Belar and Sunrise; and Marquand (*22*), *Avena strigosa glabrescens* (Schreb.) Marquand (Glabrota). Hawkeye originated as a selection from a Richland (C.I. 787)×Green Russian (C.I. 2890) cross by S. M. Dietz, of the Iowa Agricultural Experiment Station. It is an awnless, midseason, yellow oat with no outstanding differentiating character and more or less intermediate between the parent varieties. The origin and description of Richland have been reported by Burnett, Stanton, and Warburton (*3*) and Stanton, Griffee, and Etheridge (*34*). Anthony was developed by the Minnesota Agricultural Experiment Station as a selection from a Victory ×White Tartar cross. It is a midseason, white oat with erect, equilateral panicles and occasional nontwisted to slightly twisted, subgeniculate awns. Anthony is similar to the Victory type described by Marquand (*22*).

outside temperature was too high to allow a constant greenhouse temperature of approximately 70° F. Artificial light was used in the winter and during cloudy weather, in order that the light might be more nearly uniform.

With these precautions, however, a fluctuation within an infection type was sometimes observed, especially on certain varieties when inoculated with certain physiologic forms. A variation occasionally occurred when the temperature was kept constantly within the range of 68 to 72° F. and when light, soil moisture, and atmospheric humidity conditions were apparently constant, although not controlled. The most common variances were 0–1, 3–4, and vice versa. Variations from 1–2 also were infrequently observed. On certain differential varieties, when inoculated with certain physiologic forms, an M-type of infection will be produced when maintained at a temperature of 65° to 75°, while at 55° to 65° there will be produced a 0–1 type, and at 75° to 85° a 3–4 type will develop. A variation from a low to a high infection type, or vice versa, was observed only when there were great differences in temperature during the period between inoculation and the appearance of the mature uredia, and then there was always an intermediate temperature range at which an M-type would appear and remain constant. Within the temperature range in which a particular M-type appears there is no apparent evidence to indicate that it is any less constant than any other type that is influenced by temperature changes. All of the M-types studied were variable when subjected to sufficiently great temperature changes, although only a comparatively small proportion of the other infection types are apparently significantly influenced by changes in temperature or other environmental factors.

In the present investigation, a difference of at least two infection types was considered necessary to establish a new form, that is, a type 0 contrasted with a type 2, 3, 4, or M; a type 1 contrasted with a type 3, 4, or M; or a type 2 contrasted with a type 4. It was unusual when the reaction of a differential variety to a particular physiologic form varied more than two types under the normal greenhouse conditions maintained during this investigation.

FIELD TESTS OF OAT VARIETIES

A knowledge of the field reaction of varieties studied under greenhouse conditions is very desirable. From 1928 to 1931, inclusive, uniform crown-rust nurseries were grown, at one time or another, at 12 different locations in the central and southern portions of the United States. Additional varieties were grown at Ames, Iowa, in 1929 to 1932, inclusive, and at Manhattan, Kans., in 1929 and 1930. The location of the uniform crown-rust nurseries, the number of oat varieties included annually, and the names of the cooperators at each of the experiment stations where the nurseries were grown are given in table 2.

The percentages of crown-rust infection were determined according to the scale illustrated by Durrell and Parker (*12*). In addition to the differences in percentage of infection, marked differences in infection types were observed. These types are often difficult to determine because usually uredia occur in different stages of development. There are also differences in maturity of the host plants and mesothetic reactions, due possibly to the presence of more than one form.

An attempt was made to obtain the rust estimates at the time of maximum crown-rust infection; for obvious reasons, however, this could not always be accomplished. Numerical equivalents were arbitrarily assigned the 10 infection types recorded under field conditions, in order that infection coefficients might be calculated. The infection types recorded under field conditions and their numerical equivalents are as follows: 0, 0.1; 0–1, 0.2; 1, 0.3; 1–2, 0.4; 2, 0.5; M, 0.6; 2–3, 0.7; 3, 0.8; 3–4, 0.9; 4, 1.0. The coefficient of infection was then calculated by multiplying the numerical equivalent by the percentage of infection.

TABLE 2.—*Location of uniform crown-rust nurseries, number of varieties grown each of the years 1928–31, and names of cooperators at the cooperating experiment stations*

Location	Varieties grown in—				Cooperators
	1928	1929	1930	1931	
	Number	*Number*	*Number*	*Number*	
Ames, Iowa	88	100	100	50	L. C. Burnett.
Knoxville, Tenn.	88	100	100	50	S. H. Essary.
Clemson College, S.C.			100	50	W. W. Rogers.
Experiment, Ga.	88	100	100	50	R. P. Bledsoe.
Tifton, Ga.	88	100			W. J. Davis.
Gainesville, Fla.				30	A. H. Eddins.
State College, Miss.	88	100	100		L. E. Miles.
Calhoun, La.				30	John P. Gray.
Denton, Tex.	88	100	100	50	P. B. Dunkle.
Stillwater, Okla.	88	100	100	50	J. C. Ireland, C. B. Cross.
Fayetteville, Ark.				50	C. K. McClelland.
Manhattan, Kans.		100	100	50	C. O. Johnston, J. H. Parker.

IDENTIFICATION OF PHYSIOLOGIC FORMS

Hoerner (*18*), Popp (*30*), Parson (*28*), Peturson (*29*), and the writer (*24*) have, among themselves, more or less independently identified and described 15 separate physiologic forms of *Puccinia coronata avenae* occurring in North America. Each investigator, except Hoerner, employed one or more differential varieties not used by his predecessors and omitted one or more they did use. Also, each identified two or more physiologic forms not identified by his predecessors. Because each worker used a somewhat different set of differentials it is difficult to compare certain of the forms he describes. Two collections apparently representing the same physiologic form may be identified as two distinct forms when new differential varieties are employed. Many of the later forms are doubtless those that were present and probably collected by previous investigators but were not recognized as distinct forms because they lacked the differential varieties necessary to identify them. For this reason a comparison of the yearly geographic distribution of the physiologic forms reported by these various investigators would be of limited value.

An attempt has been made to adopt a standardized numeration for the 15 forms reported as occurring in North America. Hoerner's forms 1, 2, 3, and 4 (*18*) were considered the basis for this standardized numeration because of their priority. Popp (*30*) next described four forms. His forms 2 and 1 were apparently the same as Hoerner's 2 and 3, respectively, while his 3 and 4 were apparently distinct from any 2 of Hoerner's 4 forms and are, for that reason, assigned the standard key numbers 5 and 6, respectively. Likewise, standard numbers have been assigned the physiologic forms described by Parson (*28*)

and Peturson (*29*). Apparently 10 distinct forms had been identified in North America prior to this investigation. These and 5 additional forms reported by the writer in a preliminary publication (*24*) have been arranged chronologically and assigned standard numbers 1 to 15, inclusive (table 3). The first culture of crown rust that produced the infections reported for one of these standard forms was considered typical of that particular form. Two or more forms might be, and often were, isolated that produced the same infection for a particular form as a given form reported by these earlier investigators on the differential hosts they employed. In such instances the first form isolated was considered typical of the one previously reported, while additional forms were assigned standard key numbers above 15 in accordance with their parasitism on the added differential varieties. Fortunately, cultures representing forms 1 to 10, inclusive, were isolated in this investigation, and the reaction of all the standard differential varieties to each form was obtained.

TABLE 3.—*Host reactions to physiologic forms of Puccinia coronata avenae on differential varieties of Avena spp., expressed in means of types of rust infection*

Designation of physiologic forms						Reaction of differential hosts										
As recorded in literature						Avena sativa					A. sativa orientalis		A. byzantina			A. strigosa
						1	2	3	4	5	6	7	8	9	10	11
Hoerner (*18*)	Popp (*30*)	Parson (*28*)	Peturson (*29*)[1]	Murphy (*24*)	Standardized numeration	Ruakura	Green Russian	Hawkeye	Anthony	Sunrise	Green Mountain	White Tartar	Red Rustproof	Sterlsel	Belar	Glabrota
1	----	1	1	5	1	4	4	4	4	4	4	4	4	4	3	0
2	2	----	6	----	2	1	0	4	0	0	0	0	0	1	0	0
3	1	3	3	3	3	0	4	4	4	0	4	4	0	0	0	0
4	----	----	7	----	4	3	1	4	0	4	M	1	4	4	4	0
----	3	----	----	----	5	0	1	4	0	4	0	0	4	3	4	0
----	4	4	4	----	6	0	4	4	4	4	4	4	4	4	4	0
----	----	2	----	1	7	4	4	0	0	4	0	0	4	4	4	0
----	----	5	----	----	8	1	3	4	4	0	4	4	1	3	2	0
----	----	----	2	----	9	1	2	3	3	2	3	3	1	1	2	0
----	----	----	5	2	10	4	4	4	4	1	1	1	4	4	4	----
----	----	----	----	4	11	4	4	0	0	2	0	4	4	4	4	4
----	----	----	----	6	12	4	4	0	4	3	4	0	4	3	3	0
----	----	----	----	7	13	4	4	4	4	2	4	4	4	0	0	3
----	----	----	----	8	14	1	4	4	4	1	4	4	4	0	0	0
----	----	----	----	9	15	0	4	4	4	4	4	4	4	4	1	0
----	----	----	----	----	16	1	4	0	0	0	1	4	0	0	0	4
----	----	----	----	----	17	0	4	4	0	4	1	4	4	----	4	0
----	----	----	----	----	18	0	4	0	0	0	0	4	0	----	0	0
----	----	----	----	----	19	0	4	4	1	1	1	4	1	0	1	0
----	----	----	----	----	20	4	4	4	0	4	0	4	4	4	4	0
----	----	----	----	----	21	0	0	4	4	0	4	4	4	4	4	0
----	----	----	----	----	22	0	4	4	0	4	0	0	4	4	4	0
----	----	----	----	----	23	4	4	4	4	0	4	4	0	4	2	0
----	----	----	----	----	24	0	4	4	4	0	4	4	0	0	0	4
----	----	----	----	----	25	4	4	4	0	4	4	0	4	4	4	0
----	----	----	----	----	26	4	4	4	0	4	0	4	4	4	4	0
----	----	----	----	----	27	4	4	4	0	4	4	0	4	0	4	0
----	----	----	----	----	28	4	0	4	1	0	4	4	0	3	3	0
----	----	----	----	----	29	0	2	0	0	0	0	0	2	2	0	0
----	----	----	----	----	30	4	4	4	3	4	4	4	4	3	4	3
----	----	----	----	----	31	3	3	3	M	3	3	M	4	4	4	0
----	----	----	----	----	32	4	M	4	M	M	M	M	3	2	M	0
----	----	----	----	----	33	4	0	3	3	4	3	3	4	3	M	I

[1] Peturson's reactions for his forms 1, 6, 3, 2, and 5 were obtained from him directly through correspondence dated Apr. 15, 1930.

From 1927 to 1932, inclusive, 533 cultures of *Puccinia coronata avenae* were collected in the United States, Canada, and Mexico. Among these, 33 physiologic forms were identified by the specific reaction of 11 differential oat varieties. The mean infection type induced on each of the standard differential varieties by each of the 33 forms and the designation recorded in literature for each form previously reported by American investigators are presented in table 3. The reactions of Glabrota (C. I. 2630) to form 10 and of Sterisel to forms 17 and 18 are not known, because these forms have not been isolated since these varieties became available.

The reactions recorded in table 3 were determined on the first leaf of seedling plants. The second leaf infrequently showed a reaction class indicative of considerably more susceptibility than that on the first leaf of the same plant. For identification purposes the first leaf was the most sensitive and convenient, therefore only its reaction was used for differentiating physiologic forms. Each reaction represents an average for all the cultures identified as that particular form. These reactions may be grouped into three classes: *Resistant*, *mesothetic*, and *susceptible*. Then the 11 standard differential varieties can be arranged in a trichotomous key for the identification of the 33 physiologic forms.

Analytical key for the determination of physiologic forms of *Puccinia coronata avenae* determined on the basis of their parasitic behavior on differential varieties within the genus *Avena*.

Variety and behavior	*Physiologic form*
Ruakura resistant:	
Green Russian resistant:	
Hawkeye resistant	29
Hawkeye susceptible:	
Anthony resistant:	
Sunrise resistant	2
Sunrise susceptible	5
Anthony susceptible:	
Red Rustproof resistant	9
Red Rustproof susceptible	21
Green Russian susceptible:	
Hawkeye resistant:	
Glabrota resistant	18
Glabrota susceptible	16
Hawkeye susceptible:	
Anthony resistant:	
Sunrise resistant	19
Sunrise susceptible:	
White Tartar resistant	22
White Tartar susceptible	17
Anthony susceptible:	
Sunrise resistant:	
Red Rustproof resistant:	
Sterisel resistant:	
Glabrota resistant	3
Glabrota susceptible	24
Sterisel susceptible	8
Red Rustproof susceptible	14
Sunrise susceptible:	
Belar resistant	15
Belar susceptible	6
Ruakura susceptible:	
Green Russian resistant:	
Anthony resistant:	
Sunrise resistant	28
Sunrise susceptible	4
Anthony susceptible	33

Variety and behavior	*Physiologic form*
Ruakura susceptible—Continued.	
Green Russian mesothetic	32
Green Russian susceptible:	
Hawkeye resistant:	
Anthony resistant:	
Sunrise resistant	11
Sunrise susceptible	7
Anthony susceptible	12
Hawkeye susceptible:	
Anthony resistant:	
Green Mountain resistant:	
White Tartar resistant	20
White Tartar susceptible	26
Green Mountain suceptible:	
Sterisel resistant	27
Sterisel susceptible	25
Anthony mesothetic	31
Anthony susceptible:	
Sunrise resistant:	
Green Mountain resistant	10
Green Mountain susceptible:	
Red Rustproof resistant	23
Red Rustproof susceptible	13
Sunrise susceptible:	
Glabrota resistant	1
Glabrota susceptible	30

Peturson (*29*) has reported that the reaction of Green Mountain, White Tartar, Green Russian, Red Rustproof, Sterisel, and Ruakura to standard forms 1 and 3 was not influenced by temperature, but that the reaction of all these varieties, except Sterisel and Ruakura, to forms 4 and 6 was affected to some extent by temperature. He suggested 70° F. as best adapted to the identification of physiologic forms and probably most easily maintained by the average investigator.

The effect of temperature on the reaction of certain varieties to certain forms was noted early in this investigation. The reactions recorded in table 3 were determined on plants held at approximately 70° F., i.e., within the range 65°–75°. At a temperature of 85° certain forms could not be distinguished from each other, while at 55° forms could be differentiated that were indistinguishable at 70°.

In January 1933 the writer had available four greenhouse rooms in which the temperatures were automatically controlled. The mean temperature in these four rooms was 55°, 65°, 75°, and 85° F., with an allowed range for each of 50°–60°, 60°–70°, 70°–80°, and 80°–90°, respectively. The infection type produced on the differential varieties and on Victoria, Bond, and Markton infected with forms 1 and 7 when exposed to these temperatures from the time of inoculation until uredia first appeared is shown in table 4. The reaction of the varieties infected with form 1 varied only slightly. M types were produced on Hawkeye and Anthony at 55°, otherwise the reactions were not significantly affected. There was, however, an evident tendency toward a more susceptible reaction at the higher temperatures, and vice versa.

The effect of temperature on the reaction of the varieties to form 7 was striking. At 85° F. this form could not accurately be distinguished from form 1. Green Russian, Hawkeye, Anthony, Sunrise, Green Mountain, and White Tartar were resistant to form 7 at 55° but susceptible at 85°. M-types were produced on all these varieties, with the exception of White Tartar, at a temperature between which

they produced resistant and susceptible reactions. An M type would probably be produced on White Tartar at some temperature between 75° and 85°. Red Rustproof, Sterisel, and Belar were very susceptible to "scalding" at 80° or above, thereby making accurate determination of infection types very difficult, and often impossible to determine. At 55° uredia appeared 3 to 4 days later than at 70° or above.

TABLE 4.—*Infection type produced on 14 oat varieties infected with forms 1 and 7 at 55°, 65°, 75°, and 85° F.*

Varieties tested		Infection type with physiologic form—							
Name	C.I. no.	1				7			
		55°	65°	75°	85°	55°	65°	75°	85°
Ruakura	2025	3	3+	4	4+	3	3+	4	4+
Green Russian	2890	3−	3+	4	4	1	M	3+	4+
Hawkeye	2464	M	3+	4	4	0	1	M	3+
Anthony	2143	M	3−	3+	4	0	1	M	3
Sunrise	982	3+	3+	3+	4	2	M	3+	4
Green Mountain	1892	3	3	3+	4	0	0	M	3+
White Tartar	551	3+	3+	4	4	0	0	1	3
Red Rustproof	1815	3+	3+	4	4	3	3+	4	4+
Sterisel	2891	3+	3+	4	4	3	3+	4	4
Belar	2760	3	3+	3+	4	3	3+	4	4
Glabrota	2630	I	I	0	0	I	I	0	0
Victoria	2401	0	0	1−	1	I	0	0	0
Bond	2733	I	I	0	0	I	I	0	0
Markton	2053	3+	3+	4	4	3+	4	4	4+

NATURE OF PHYSIOLOGIC FORMS IDENTIFIED

The 33 physiologic forms identified differed greatly in versatility[6] and pathogenicity,[7] although groups of somewhat similar forms may be discerned. By assigning numbers 1 to 11, respectively, to the standard differential varieties in table 3, a descriptive formula may be given each form by writing the numbers representing the varieties resistant to it. These formulas, arranged in the order of versatility and pathogenicity, are presented in table 5. They are more convenient and accurate for use in identifying forms than is the analytical key previously described.

Physiologic forms 30 and 1 are the most aggressive and virulent forms identified. Bond, Victoria (C.I. 2401), and Victoria (Scasso) (C.I. 2764) are the only varieties resistant to form 30. Form 1 is slightly less aggressive than form 30 in that it is unable to induce a susceptible reaction in Glabrota. This form, however, is apparently of much greater economic importance because of its prevalence and wide distribution, as will be shown later. The seedling reaction to form 1 has been determined for approximately 300 varieties and selections, and only 4 varieties—Glabrota, Bond, and the 2 Victorias—were resistant to it.

[6] "Versatility" applies to the number of oat varieties that a form is capable of infecting readily. Where the number is comparatively large the form is referred to as "aggressive", and where the number is relatively small the form is referred to as "restricted."

[7] "Pathogenicity" refers to the relative vigor of rust attack as expressed by the infection type. A form inducing a susceptible reaction in a given variety is described as "virulent", while one causing a resistant reaction or that is incapable of producing any evidence of infection is "nonvirulent."

TABLE 5.—*Descriptive formulas for the physiologic forms of Puccinia coronata avenae*

Physiologic form no.	Numerical formula [1]	Physiologic form no.	Numerical formula [1]
30		27	4, 7, 9, 11.
1	11.	4	2, 4, 7, 11 (6).
33	2 (10).	8	1, 5, 8, 10, 11.
31	11 (4, 7).	14	1, 5, 9, 10, 11.
6	1, 11.	7	3, 4, 6, 7, 11.
32	9, 11 (2, 4, 5, 6, 7, 10).	22	1, 4, 5, 7, 11.
10 [2]	5, 6, 7.	24	1, 5, 8, 9, 10.
13	5, 9, 10.	28	2, 4, 5, 8, 11.
15	1, 10, 11.	5	1, 2, 4, 6, 7, 11.
25	4, 7, 11.	3	1, 5, 8, 9, 10, 11.
26	4, 6, 11.	9	1, 2, 5, 8, 9, 10, 11.
12	3, 7, 11.	19	1, 4, 5, 6, 8, 9, 10, 11.
11	3, 4, 5, 6.	16	1, 3, 4, 5, 6, 8, 9, 10.
23	5, 8, 10, 11.	18 [3]	1, 3, 4, 5, 6, 8, 10, 11.
17 [3]	1, 4, 6, 11.	2	1, 2, 4, 5, 6, 7, 8, 9, 10, 11.
21	1, 2, 5, 11.	29	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11.
20	4, 6, 7, 11.		

[1] Numbers in this column refer to the standard differential varieties as they are numbered in table 3. The varieties represented by the numbers included in a particular physiologic form formula are resistant to that form, except those indicated by numbers within parentheses, which represent varieties that produce a mesothetic reaction.

[2] Reaction of Glabrota to form 10 is unknown.

[3] Reaction of Sterisel to forms 17 and 18 is unknown.

Form 29 is in direct contrast to form 30 in that all of the standard differential varieties are resistant to the one and susceptible to the other. The remaining 30 forms are fairly evenly distributed between these two extremes.

Mesothetic or M types of infection were produced by forms 4, 31, 32, and 33. These appeared constant under the conditions of this experiment, but a lower or higher temperature range probably would affect them, as previously stated.

Apparently there is slight correlation between versatility and pathogenicity. A very aggressive form is often completely nonvirulent on certain varieties, whereas a very restricted form will attack these same or other varieties with great virulence. Glabrota, for example, is extremely resistant to the very aggressive form 1 and completely susceptible to the restricted form 16.

Raines (*31*) probably was the first to note that cultures of crown rust may vary in their ability to produce telia. A culture collected in the vicinity of New York City produced teliospores only moderately, whereas one from Ames, Iowa, grown at the same time, under similar conditions, and on the same host material, produced teliospores abundantly. By selection, Raines secured 36 cultures 20 of which produced no teliospores under greenhouse conditions, and 35 cultures 30 of which produced more than 50 percent of telia.

Parson (*28*) noted that certain of his physiologic forms consistently produced teliospores about 3 weeks after inoculation, while others were never observed to produce teliospores. He did not agree with the opinion of Parker (*27*) that early production of teliospores was definitely correlated with the resistance of the host plant. He suggested instead that early formation of teliospores is possibly characteristic of restricted, "narrowly specialized" forms.

Frenzel (*15*) observed his forms 2, 9, 10, 11, 17, and 20 for teliospore production. He found that forms 2 and 10 consistently produced teliospores earlier and more abundantly than the remaining four forms. Forms 9 and 11 produced teliospores later and less abundantly,

whereas in forms 17 and 20 no teliospores developed until 38 days following inoculation. Frenzel found that teliospores appeared first on resistant plants. Forms having a strong tendency toward teliospore production, such as 2 and 10, would form teliospores on susceptible plants a few days later than on resistant ones, although forms with a slight tendency toward teliospore production, such as 9 and 11, formed teliospores only on certain resistant plants.

Differences in rate of teliospore formation between certain forms were noted at the beginning of the present investigation. Observations of different cultures representing the same physiolgic form were not always consistent, however. On April 26, 1929, 13 cultures were collected from artificially inoculated *Rhamnus* leaves. These cultures were purified by repeated single-uredium isolations and identified in December 1929. On the basis of the reaction of 33 varieties (including all of the standard differentials except Sterisel), each of these 13 cultures behaved like physiologic form 18. Seedling plants of the varieties were inoculated December 6, 1929, while in the two-leaf stage, and were maintained under the same environmental conditions at 68° to 72° F. On December 16, eight of the cultures had produced telia on Red Rustproof (C.I. 1079), Red Rustproof (C.I. 1805), Cowra, Iowa No. 69, and Magistral (C.I. 2460). These five varieties showed a type 1 infection with each of the 13 cultures, whereas the remaining 18 resistant varieties showed a type 0. On December 20 these same 8 cultures had produced some telia on each of the 10 susceptible varieties, but the remaining 5 cultures had not then produced telia on any of the 33 varieties. Two of the five remaining cultures began to produce telia on certain of the five resistant varieties mentioned above on December 27, and on December 30 all five varieties were bearing some telia. It was not until January 2, 1930, that telia began to appear on the susceptible varieties inoculated with these same 2 cultures, and they had not appeared on all the susceptible varieties until January 8. On January 10, 35 days after inoculation, telia had not appeared on any of the 33 varieties inoculated with the remaining 3 cultures. This same experiment was repeated twice during the spring of 1930 with very similar results.

Apparently physiologic form 18 could be divided into 3 subforms: (1) A form producing telia rapidly and represented by 8 of the 13 cultures; (2) a form producing telia slowly and represented by 2 cultures; and (3) another form apparently not producing telia on seedling plants and represented by 3 cultures. The cultures representing subform 1 frequently produced telia without any evidence of uredial development.

On the basis of observations made, 10, 14, 21, 28, and 35 days following inoculation of seedling plants of the differential varieties, the 33 physiologic forms described in table 3 may be similarly classified, as follows: Group 1—2, 3, 5, 8, 9, 16, 18, 19, 22, 23, 24, 28, 29; group 2—2, 3, 4, 5, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 27, 32; and group 3—1, 6, 12, 18, 25, 26, 30, 31, 32, 33.

Six of the 33 forms (2, 3, 5, 8, 16, and 19) were represented by cultures in groups 1 and 2, two forms (12 and 32) were represented by cultures in groups 2 and 3, and form 18 was represented in groups 1, 2, and 3.

On the basis of parasitic reaction on the differential varieties and rapidity of telia production, 43 physiologic forms could be differen-

tiated among the 533 cultures studied. Acceptance of rate of telial production as a differentiating character for identifying physiologic forms would, however, entail much additional time and labor without apparently adding much to our knowledge of the pathogenicity and versatility of the form included. Hence, it seems preferable to omit rate of telial production as a character on which to identify physiologic forms and to employ it for differentiation of subforms. Whenever practicable, the rate of telial production of all cultures identified should be observed, especially so when a new physiologic form is present.

There is apparent a positive correlation between rapidity of telial production and restricted forms. A comparison of the above classification with the physiologic-form formulas previously presented will show that most of the forms exhibiting early telia production are, in general, the more restricted ones. Obviously the reaction of 11 standard differential varieties is not a wholly dependable criterion as to whether a physiologic form is aggressive or restricted. The reaction of 33 differential varieties to 13 forms and 266 varieties to 6 of these same forms has not, however, materially affected this ranking.

A discussion of the relation between type of infection and rapidity of telial production is presented under the heading "Reaction of Oat Varieties."

PHYSIOLOGIC FORMS COLLECTED FROM RHAMNUS

Sixty-five collections of crown rust were obtained from naturally and artificially inoculated *Rhamnus* species in 1928, 1929, and 1930. An equal number of cultures isolated from these collections were identified and found to represent 14 physiologic forms. The distribution of the forms obtained from *Rhamnus* according to the species from which they were collected is given in table 6.

TABLE 6.—*Physiologic forms identified and number of cultures collected from different species of Rhamnus in 1928, 1929, and 1930*

Collected from—	Cultures identified as physiologic form—														Total isolations	
	1	2	3	4	5	6	8	13	14	15	16	18	19	23	Cultures	Forms
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
R. cathartica	----	----	13	1	----	----	1	----	----	----	----	----	----	----	15	3
R. chlorophora	----	----	----	----	----	----	----	----	----	----	----	----	1	----	1	1
R. infectoria	3	1	4	----	1	----	1	----	1	1	----	10	2	1	25	10
R. lanceolata	9	----	----	----	----	----	----	----	----	----	----	----	----	----	9	1
R. montana	----	----	----	----	----	----	----	----	1	----	----	3	2	----	6	3
R. spp. (from Peiping, China)	----	----	----	----	----	1	----	----	----	----	----	----	----	----	1	1
R. spp. (from Siberia)	----	----	----	----	----	----	----	----	----	1	----	----	----	----	1	1
R. tinctoria	----	3	1	----	----	----	1	1	----	----	1	----	----	----	7	5
Total	12	4	18	1	1	1	3	1	2	2	1	13	5	1	65	14

Eight cultures, identified as form 3, collected from *Rhamnus cathartica*, and 6, identified as form 1, collected from *R. lanceolata*, were from naturally inoculated plants growing under field conditions. The remaining 51 cultures were collected from artificially inoculated plants growing under greenhouse conditions.

Forms 14, 15, and 18 were collected only from artificially inoculated *Rhamnus*, and forms 6, 8, 13, 19, and 23 either from artificially inoculated *Rhamnus* or from oat plants growing near naturally inoculated

Rhamnus. In the light of the investigations conducted by Dietz (*10*), Craigie (*5, 6, 7, 8, 9*), Hanna (*17*), Newton, Johnson, and Brown (*26*), Stakman, Levine, and Cotter (*33*), Allen (*1*), Waterhouse (*36*), and others, it seems probable that certain of these forms, particularly those of rare occurrence, may have arisen by hybridization or segregation.

On September 23, 1928, some nearly mature volunteer plants of Hawkeye oats were collected at Ames, Iowa. They were heavily infected with crown rust, both in the telial and uredial stages. Nine different single-uredium cultures were identified. Six of these proved to be physiologic form 1 and three physiologic form 3. Early in March 1929 the telial material of this same collection was used to inoculate plants of *Rhamnus infectoria* and *R. montana*. Abundant infection was secured on both. A total of 16 unopened aecial cups, 13 from *R. infectoria* and 3 from *R. montana*, were carefully picked with sterilized forceps. The aeciospores from each were used to inoculate Markton oat plants, and the progeny of the single-uredium isolations were identified in the usual manner. Thirteen cultures obtained from the same number of aecial cups from *R. infectoria* were identified as follows: 9 were form 18; 2 were form 1; 1 was form 3; and 1 was form 19. The 3 cultures from *R. montana* were identified as form 18.

Form 1 does not produce teliospores readily on growing plants, but telia have been observed on maturing adult plants, especially when held under somewhat adverse environmental conditions. It is probable, therefore, that teliospores representing both forms 1 and 3 were present in the collection. One or both forms are apparently heterozygous, and either parental form might have reappeared on *R. infectoria* as a progeny of the original forms or as segregates resulting from hybridization. Forms 18 and 19 apparently originated by hybridization between forms 1 and 3, or as segregates from one or both forms. The fact that teliospores were collected from a pure-line selection of Hawkeye (C.I. 2464), which is highly resistant to form 18, is further evidence that this form was not present in the original collection.

In the spring of 1929 teliospores of forms 2 and 7 were produced under greenhouse conditions and allowed to mature at a temperature of 60° to 65° F. Leaves bearing these teliospores were collected, dried, and then stored over the winter in burlap bags hanging outside the greenhouse. In March 1930 an attempt was made to inoculate *Rhamnus alnifolia* L'Hér., *R. caroliniana* Walt., *R. cathartica*, *R. chlorophora* Dipp., *R. davurica* Pall, *R. frangula* L., *R. infectoria*, *R. koraiensis* Schneid., *R. lanceolata*, *R. purshiana* DC., *R. smithii* Greene, *R. tinctoria*, *R. utilis* Decaisne, and unidentified *Rhamnus* species from Peiping, China, and Siberia. Apparently the teliospores of form 7 did not germinate; at least, there was no evidence of infection on any of the species inoculated with this form. The absence of infection resulting from the inoculation with form 7 frustrated an attempt to hybridize the two forms by mixing their pycnial exudates.

All the species inoculated with form 2, except *Rhamnus caroliniana*, *R. frangula*, and *R. davurica*, showed some sign of infection. Necrotic areas were produced on *R. chlorophora*, *R. purshiana*, *R. utilis*, and the *Rhamnus* species from China and Siberia. Normal spermogonia with no aecia were produced on *R. alnifolia*, *R. lanceolata*, and *R. smithii*. Normal spermogonia and aecia were produced on *R. cathartica*, *R.*

infectoria, and *R. tinctoria*. The infection on all species, except *R. infectoria* and *R. tinctoria*, was slight. For this reason the apparently immune species *R. caroliniana*, *R. frangula*, and *R. davurica* might have escaped infection. This, however, seems improbable because there were 5 individual plants of *R. davurica*, 3 of *R. caroliniana*, and 2 of *R. frangula*. It is possible that normal aecia would have developed on *R. alnifolia*, *R. lanceolata*, and *R. smithii* had the nectar of the spermogonia been mixed. Unfortunately, this was not done. The infected *Rhamnus* plants were kept separate in muslin compartments but were not protected from greenhouse insects and air currents.

A total of 14 unopened aecia, 5 each from *Rhamnus infectoria* and *R. tinctoria* and 4 from *R. cathartica*, were collected and aeciospores from each of these used to inoculate Markton plants. The 14 cultures were stored in the uredial stage until the following winter. Single-uredium cultures were then isolated from each culture and identified in the usual manner. The 5 from *R. infectoria* were identified as forms 2, 3, 8, 14, and 23, each culture representing a different form. The 5 cultures from *R. tinctoria* were found to represent 3 forms, 3 being form 2 and 1 each forms 3 and 8. Two of the cultures from *R. cathartica* were identified as form 3 and one each as forms 4 and 8. Among cultures from the 14 cups resulting from inoculation with physiologic form 2, 6 physiologic forms were identified. Forms 2 and 3 were each found in 4 aecial cups, form 8 in 3, and forms 4, 14, and 23 each in 1 aecial cup. Physiologic form 2 evidently is heterozygous.

Additional single-uredium isolations from cultures originating from single aecial cups disclosed the fact that a single aecial cup apparently contains only one form.

These data from naturally and artificially inoculated *Rhamnus* also indicate that certain *Rhamnus* species may have a differential reaction; that is, certain species tend to harbor specific forms, while others harbor many forms. The numbers are too small, however, to support definite conclusions.

PREVALENCE AND GEOGRAPHIC DISTRIBUTION OF PHYSIOLOGIC FORMS

The prevalence and geographic distribution of physiologic forms of crown rust are of considerable interest, especially to the plant breeder. In the period from 1927 to 1932, inclusive, 533 cultures collected from 35 States and Provinces in the United States, Mexico, and Canada have been identified and studied. Although this is a comparatively short period and the number of cultures is small, these facts should be indicative of the prevalence and distribution of the forms present during that time.

SURVEY OF 1927

Six physiologic forms were identified among 10 single-uredium cultures, isolated from an equal number of collections obtained in 1927.[8] The distribution of these forms among 7 States in the United States and 1 Province in Canada is shown in table 7. The collections were all from naturally inoculated oats growing under field conditions. One collection from Ste. Anne de la Pocatière, Quebec, was obtained

[8] Nine of the collections secured in 1927 were furnished by L. D. Leach, now junior plant pathologist, University of California, who made a preliminary study of physiologic specialization and identified three physiologic forms. Unpublished data.

from Victory oats growing near infected *Rhamnus cathartica*. Five cultures were identified as form 7. This form was apparently prevalent throughout Iowa, Missouri, Kansas, and Oklahoma in 1927. Form 3 probably was disseminated from the infected *R. cathartica* bushes near which it was collected in Quebec. Form 1 was collected by the writer in October from volunteer oats near Mason City, Iowa. Owing to the limited number of cultures identified little significance can be given to the distribution and prevalence of the forms identified in 1927.

TABLE 7.—*Distribution of physiologic forms of Puccinia coronata avenae in the United States and Canada in 1927*

Region and State or Province	Collections of physiologic form—						Total isolations	
	1	3	7	10	11	12	Cultures	Forms
Southern Great Plains:	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
Texas						1	1	1
Oklahoma			1				1	1
Kansas			2				2	1
South-central region:								
Missouri			1				1	1
North-central region:								
Iowa	1		1				2	2
Illinois					1		1	1
Northern Great Plains:								
North Dakota				1			1	1
Canada:								
Quebec		1					1	1
Total	1	1	5	1	1	1	10	6

SURVEY OF 1928

Form 1 was by far the most widespread and prevalent form in 1928 (table 8). It was the predominating form in the southern Great Plains and in the south-central, north-central, and southeastern regions of the United States. Form 1 was not represented in cultures from the northeastern region or Canada. Four of the cultures representing form 1 were collected from naturally inoculated *Rhamnus lanceolata* in Iowa. Three cultures of form 3—two from Iowa and one from Nebraska—were from naturally inoculated *R. cathartica*. Form 3 was also collected from naturally infected oat plants in Iowa, Ohio, Ontario, and West Virginia, but in each instance *R. cathartica* was reported as growing nearby. Just why form 7, the most prevalent in 1927, should appear only in southern California and western Texas is uncertain. Forms 13, 14, and 15 were new ones collected only from artificially inoculated *R. tinctoria*, *R. montana*, and *R. infectoria*, respectively.

TABLE 8.—*Distribution of physiologic forms of Puccinia coronata avenae in the United States and Canada in 1928*

Region and State or Province	Collections of physiologic form—						Total isolations	
	1	3	7	13	14	15	Cultures	Forms
Western States:	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
California	2		3				5	2
Oregon	1						1	1
Southern Great Plains:								
Texas	4		2				6	2
Oklahoma	1						1	1
South-central region:								
Missouri	1						1	1
Mississippi	4						4	1
Southeastern region:								
Florida	1						1	1
Georgia	4						4	1
Tennessee	1						1	1
West Virginia		1					1	1
North-central region:								
Iowa	10	3		1	1	1	16	5
Northern Great Plains:								
Nebraska		1					1	1
North Dakota	1						1	1
Northeastern region:								
Ohio		1					1	1
Canada:								
Ontario		1					1	1
Total	30	7	5	1	1	1	45	6

SURVEY OF 1929

Physiologic forms 7 and 1 were without doubt the most prevalent forms in 1929 (table 9). Form 7 was represented in 76 cultures collected in 14 States and form 1 in 48 from 13 States. These forms were apparently the predominating ones in all regions from which collections were obtained except the northern Great Plains. Seven of the cultures from Iowa, representing form 1, were collected from *Rhamnus;* 4 from *R. lanceolata;* and 3 from *R. infectoria.* One of the cultures from *R. lanceolata* was from a naturally inoculated plant; the remaining 6 were from artificially inoculated plants. Eleven of the twenty cultures from Iowa, identified as form 3, were collected from *Rhamnus;* 5 from naturally inoculated *R. cathartica;* and 3 each from *R. cathartica* and *R. infectoria,* artificially inoculated. The remaining 17 cultures, representing form 3, were collected in localities where *R. cathartica* is prevalent. Two cultures from Iowa, representing forms 16 and 19, were collected from artificially inoculated *R. tinctoria* and *R. infectoria,* respectively. All of the cultures identified as form 18 were collected from artificially inoculated *Rhamnus:* 10 from *R. infectoria* and 3 from *R. montana.*

TABLE 9.—*Distribution of physiologic forms of Puccinia coronata avenae in the United States in 1929*

Region and State or Province	Collections of physiologic form—								Total isolations	
	1	3	7	12	16	17	18	19	Cultures	Forms
Western States:	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
Oregon	1		3						4	2
Southern Great Plains:										
Texas	3		3						6	2
Oklahoma	5		1						6	2
Kansas	5		15			1			21	3
South-central region:										
Missouri		1	3			2			6	3
Mississippi	5		4						9	2
Southeastern region:										
Florida	5		4						9	2
Georgia	2		7						9	2
Alabama	2								2	1
Tennessee	6		6						12	2
Virginia	2		4						6	2
West Virginia	1	3	3		7	2			16	5
North-central region:										
Iowa	10	20	19	2	7	3	13	2	76	8
Minnesota	1		3						4	2
Northern Great Plains:										
South Dakota			1						1	1
North Dakota		4							4	1
Total	48	28	76	2	14	8	13	2	191	8

SURVEY OF 1930

Twenty-one forms were identified among 112 cultures collected in 1930 from 17 States in the United States and 3 Provinces in Canada (table 10). Fifteen of these were forms not previously isolated by the writer. The discovery of so many forms previously unknown probably was partly due to the extensive area from which collections were obtained. Cultures were procured from Florida, Maine, Quebec, Ontario, Manitoba, Oregon, Texas, and many intervening States. Also, as previously stated, a number of new forms apparently resulted from hybridization or segregation on artificially inoculated *Rhamnus* species.

TABLE 10.—*Distribution of physiologic forms of Puccinia coronata avenae in the United States and Canada in 1930*

Region and State or Province	Collections of physiologic form—											
	1	2	3	4	5	6	7	8	13	14	15	19
Western States:	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
Oregon	2			2								
Southern Great Plains:												
Texas	2			1								
Oklahoma	2			1	1							
Kansas	2						2					
South-central region:												
Mississippi		1										
Southeastern region:												
Florida	4											
Georgia	8											
Tennessee							2					
West Virginia	2		1						1			
North-central region:												
Iowa	2	4	4	2	1	3		3		1	1	4
Illinois												
Wisconsin												2
Minnesota												
Northern Great Plains:												
North Dakota												
Northeastern region:												
New Jersey												
New York		2										
Maine		2										
Canada:												
Manitoba		2	2			1						
Ontario		2										
Quebec			1					2				
Total	24	13	8	6	2	4	4	5	1	1	1	6

Region and State or Province	Collections of physiologic form—									Total isolations	
	20	21	22	23	24	25	26	27	28	Cultures	Forms
Western States:	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
Oregon			2							6	3
Southern Great Plains:											
Texas										3	2
Oklahoma	3									7	4
Kansas										4	2
South-central region:											
Mississippi								1		2	2
Southeastern region:											
Florida										4	1
Georgia										8	1
Tennessee				2			2			6	3
West Virginia										4	3
North-central region:											
Iowa	2			1		4				32	13
Illinois									2	2	1
Wisconsin			2							4	2
Minnesota					2	1				3	2
Northern Great Plains:											
North Dakota									3	3	1
Northeastern region:											
New Jersey				2						2	1
New York										2	1
Maine										2	1
Canada:											
Manitoba	2	1			2		2			12	7
Ontario										2	1
Quebec				1						4	3
Total	7	1	4	6	4	5	4	1	5	112	21

Form 1 was the most widely distributed and prevalent of all in 1930. It was, however, apparently limited almost entirely to the region where it may hibernate on fall-sown or volunteer oats. Two cultures from Iowa were identified as form 1. One of these was collected from naturally inoculated *Rhamnus lanceolata* and the other from oats growing near these infected bushes. Apparently form 1 spread northward but little, neither was it widely disseminated from *Rhamnus*. The next most prevalent and widely distributed was form 2, a form standing in direct contrast to form 1 insofar as virulence and aggressiveness are concerned. Except for one culture from Mississippi, it was collected only in the Northern States and Canada.

Form 2 was no doubt dependent upon *Rhamnus* for dissemination in that year. Four of the cultures from Iowa, representing form 2, were from artificially inoculated *Rhamnus;* one was from *R. infectoria* and three were from *R. tinctoria*. Forms 20, 22, 23, and 26 were limited in prevalence but widespread in distribution. Two forms, 14 and 15, were collected only from artificially inoculated *Rhamnus* and, as previously stated, probably originated as a result of hybridization or segregation.

Forms 3, 6, 8, 19, 21, 24, 25, and 28 were collected only in the spring-sown-oat region, whereas forms 4, 5, 7, 13, and 28 were most prevalent in the winter-oat States. Form 7, the most prevalent in 1929, was apparently very limited in distribution in 1930, being collected only in Kansas and Tennessee, where it was prevalent in 1929.

Four cultures of form 3 from Iowa were collected from artificially inoculated *Rhamnus*, two from *R. cathartica* and one each from *R. infectoria* and *R. tinctoria*. A single culture of each of forms 4, 5, 6, 14, 15, and 23, from Iowa, were collected from artificially inoculated *R. cathartica*, *R. infectoria*, *R.* spp. (from Peiping), *R. infectoria*, *R.* spp. (from Siberia), and *R. infectoria*, respectively. Three cultures of form 8, from Iowa, were collected from artificially inoculated *R. cathartica*, *R. infectoria*, and *R. tinctoria*. Four cultures from Iowa, representing form 19, were obtained from artificially inoculated *Rhamnus*, one each from *R. chlorophora* and *R. infectoria*, and two from *R. montana*.

SURVEY OF 1931

Five forms, not previously identified by the writer, were isolated from 127 cultures collected from 16 States in the United States and Mexico and 3 Provinces in Canada in 1931. In addition to these, 11 forms previously isolated were recovered, making a total of 16 forms identified among the 1931 collections (table 11). Form 1 was again the most prevalent, although form 7 was equal in distribution. Both forms were limited in occurrence mainly to the region of winter-oat production. Forms 4, 11, 16, 20, 24, 25, and 30 were limited to the spring-sown-oat area, while forms 2, 6, and 29 were found only in the Northern States and Quebec. Form 30, the most aggressive and virulent form so far identified, was represented by one culture from Florida.

TABLE 11.—*Distribution of physiologic forms of Puccinia coronata avenae in the United States, Mexico, and Canada in 1931*

Region and State or Province	Number of collections of physiologic form—																Number of total isolations	
	1	2	3	4	6	7	9	11	16	20	24	25	29	30	31	32	Cultures	Forms
Western States:																		
California	1									2		2					5	3
Oregon				2		2									1		5	3
Mexico:																		
Coahuila						2											2	1
Guanajuato						1											1	1
Querétaro	1			1		1											3	3
Southern Great Plains:																		
Texas	17					1	1			3					1		23	5
Oklahoma				1		4											5	2
Kansas	6					2									1		9	3
South-central region:																		
Louisiana	1		1			3				3							8	4
Arkansas	1														1		2	2
Missouri	3															2	5	2
Southeastern region:																		
Florida	9						1	1		3			1		1		16	6
Georgia	5			1		3		3									12	4
Tennessee				1									1				2	2
North-central region: Iowa	9					1	4						1				15	4
Northern Great Plains: North Dakota			2		1												3	2
Northeastern region: New York													5				5	1
Canada:																		
Manitoba															2		2	1
Quebec		1											1			2	4	3
Total	53	1	3	6	1	20	5	1	4	8	3	2	8	1	6	5	127	16

SURVEY OF 1932

Nine forms were isolated from 48 cultures collected from 16 States in the United States and 1 Province in Canada in a preliminary study of the collections obtained in 1932 (table 12). All except form 33 had been collected in previous years. Forms 1 and 7 continued to be the most widely distributed. Form 16, prevalent in Georgia and Florida in 1931, was the next most widely distributed. None of the cultures was collected from *Rhamnus*, although one culture from Iowa, representing form 3, was collected from oats growing near infected *Rhamnus cathartica*.

Form 33 is important because it is the only one known to be capable of producing a susceptible reaction on Bond. The history of form 33 indicates that it probably originated as a mutant in a culture representing form 1. A single-uredium culture, isolated from a collection obtained at Temple, Tex., in June 1932, was identified in November as form 1. The culture was then transferred to another greenhouse and increased for use in a study of inheritance of resistance to form 1. Successive generations of the cultures were used to inoculate hybrid plants of which Bond was one parent. The Bond parent was used as a check and consistently produced a nearly immune reaction until late in January 1933 when a single large uredium was observed on one Bond plant. This uredium was increased and the resulting culture identified as form 33. Additional single-uredium cultures from the same original collection were all identified as either form 1 or 7. Bond has consistently produced a susceptible reaction to form 33, although Green Russian (C.I. 2890), Glabrota, and the two Victoria varieties have been immune or nearly immune.

TABLE 12.—*Distribution of physiologic forms of Puccinia coronata avenae in the United States and Canada in 1932*

Region and State or Province	Collections of physiologic form—									Total isolations	
	1	3	4	6	7	16	25	29	33	Culture	Forms
Western States:	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No*	*No.*	*No.*	*No.*	*No.*
Oregon					2					2	1
Southern Great Plains:											
Texas	2				1					3	2
Kansas	1				1		1			3	3
South-central region:											
Louisiana	1									1	1
Arkansas	1			1		1				3	3
Southeastern region:											
Florida	1			1						2	2
Georgia	2					1				3	2
Tennessee	2				2	1				5	3
North-central region:											
Iowa	3	1	1	3	1				1	10	6
Illinois	1				1	1				3	3
Indiana					1					1	1
Wisconsin								1		1	1
Michigan	1				2					3	2
Northern Great Plains:											
North Dakota	1									1	1
Northeastern region:											
Pennsylvania					1	1				2	2
New York					3			1		4	2
Canada:											
Manitoba								1		1	1
Total	16	1	1	5	15	5	1	3	1	48	9

SUMMARY OF SURVEY

A total of 533 single-uredium cultures were isolated from collections obtained in 29 States in the United States, 3 States in Mexico, and 3 Provinces in Canada, in the 6-year period 1927–32. Thirty-three distinct physiologic forms were identified among these 533 cultures by the reaction of the standard differential hosts previously described. The distribution and prevalence of these forms among the 35 States and Provinces are given in table 13.

A total of 22 physiologic forms have been identified among 151 cultures collected in Iowa in the period 1927–32. Sixty-one of these cultures were collected from naturally and artificially inoculated *Rhamnus* plants, 89 from naturally inoculated oat plants growing under field conditions, and 1 from artificially inoculated oats growing under greenhouse conditions. All except 3 of the cultures from *Rhamnus* and 52 of those from oats were collected at Ames, Iowa. Fourteen of the 22 forms from Ames were identified among the cultures from *Rhamnus* and 13 among those from oats. Although forms 1, 6, 16, and 19 were collected from oats at Ames, it is possible that they were initially disseminated from artificially inoculated *Rhamnus*. Hence only forms 1, 3, 7, 9, 12, 17, 20, 26, and 29 can be considered definitely as occurring naturally in Iowa. These 9 forms were represented in 32 cultures collected in parts of Iowa other than Ames or near the *Rhamnus* nursery at Ames. Therefore, in a discussion of the natural distribution of physiologic forms in the United States, consideration must be given to the fact that 14 of the 21 forms collected in Iowa may have been dependent upon *Rhamnus* for their dissemination and 12 of these dependent upon artificially inoculated *Rhamnus* species. As previously stated, form 33 probably originated as a mutation.

TABLE 13.—*Distribution of physiologic forms of Puccinia coronata avenae in the United States, Canada, and Mexico, 1927–32, inclusive*

Region and State or Province	Number of collections of physiologic form—																													Number of total isolations	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	Cultures	Forms
Western States:																																			
California	3						3													2					2									10	4
Oregon	4			4			7															2								1			18	5
Mexico:																																			
Coahuila							2																											2	1
Guanajuato							1																											1	1
Querétaro	1			1			1																											3	3
Southern Great Plains:																																			
Texas	28			1			7		1			1								3										1				42	7
Oklahoma	8			2	1		6													3														20	5
Kansas	14						22										1								1					1				39	5
South-central region:																																			
Louisiana	2		1				3													3														9	4
Arkansas	2					1										1														1				5	4
Missouri	4		1				4										2															2		13	5
Mississippi	9	1					4																				1							15	4
Southeastern region:																																			
Florida	20					1	4				1					1							3							1		1		32	8
Georgia	21			1			10									4																		36	4
Alabama	2																																	2	1
Tennessee	9			1			10									1							2			2			1					26	7
Virginia	2						4																											6	2
West Virginia	3		5				3						1			7	2																	21	6
North-central region:																																			
Iowa	35	4	28	3	1	6	22	3	4		2	1	2	2	7	3	13	6	2			1		4				1				1	151	22
Illinois	1						1			1					1												2						6	5
Indiana							1																											1	1
Wisconsin																			2			2							1				5	3
Minnesota	1						3																	2	1								7	4
Michigan	1						2																											3	2
Northern Great Plains:																																			
Nebraska			1																															1	1
South Dakota							1																											1	1
North Dakota	2		6			1				1																		3					13	5
Northeastern region:																																			
Ohio			1																															1	1
Pennsylvania							1									1																		2	2
New Jersey																							2											2	1
New York		2					3																						6					11	3
Maine		2																																2	1
Canada:																																			
Manitoba		2	2			1														2	1			2		2			1		2			15	9
Ontario		2	1																															3	2
Quebec		1	2					2															1						1			2		9	6
Total	172	14	48	13	2	10	125	5	5	1	2	3	2	2	2	23	8	13	8	15	1	4	6	7	8	4	1	5	11	1	6	5	1	533	33

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Physiologic forms 1 and 7 were by far the most prevalent and widely distributed of any during the period of this investigation. Form 1 was represented by 172 cultures collected in 21 States and Provinces, while form 7 was represented by 125 cultures from 24 States and Provinces. Twelve of the cultures indentified as form 1 were collected from artificially and naturally inoculated *Rhamnus*, while the remaining 160 cultures were collected from naturally inoculated oats growing under field conditions. All of the 125 cultures, representing form 7, were from naturally infected oat plants. Except in 1928, forms 1 and 7 were very similar in distribution and prevalence. In that year they were collected from the same regions, but form 1 was much more prevalent. Both forms were found to hibernate on fall-sown and volunteer oats in the South and on the Pacific coast as far north as Astoria, Oreg. Apparently, forms 1 and 7 spread northward in the spring and summer into the spring-oat region. In addition, form 1 is disseminated by naturally inoculated *Rhamnus lanceolata* in the lower Mississippi Valley. All cultures collected from naturally inoculated *R. lanceolata* have been identified as form 1.

Dietz and Leach (*11*), in describing the distribution of *Rhamnus lanceolata*, state:

> Its northern limit is the central parts of Iowa, Illinois, and Indiana, and the southern parts of Ohio and Pennsylvania, although along the rivers it may be found somewhat north of this line. It is commonly found as far south as Alabama and Texas, although in the Southern States it is largely replaced by *R. caroliniana*.

Form 7 is seemingly dependent upon hibernation for its survival; at least, it was not collected from naturally or artificially inoculated *Rhamnus*. The fact that forms 1 and 7 consistently appeared each year in the southern oat region and in decreasing prevalence northward seems to be further proof that these two forms hibernate in the fall-sown-oat region and spread northward in the spring and early summer. Form 1 was collected in 1 State and form 7 in 3 States in Mexico in 1931. With the exception of form 4, these were the only forms found in Mexico in 1931.

Form 3 was the next most prevalent and widely distributed. It and forms 1 and 7 were the only ones collected and identified in each of the years during the period 1927–32. With the exception of one culture collected on May 27, 1931, at Calhoun, La., form 3 was always collected in the spring-oat region from either naturally or artificially inoculated *Rhamnus* or from oats growing near naturally inoculated *R. cathartica*. A total of 48 cultures, representing form 3, were collected from 7 States in the United States and 3 Provinces in central and eastern Canada. Of these 48 cultures, 18 were collected from artificially and naturally inoculated *Rhamnus*. All the cultures collected from naturally inoculated *R. cathartica* were identified as form 3. *R. cathartica*, although a native of Europe, is widely grown as a hedge plant in the upper Mississippi Valley and the Northeastern States, where it has escaped from cultivation and become naturalized. Form 3 probably was almost entirely dependent upon *R. cathartica* and possibly other species of *Rhamnus* for its initial spring appearance. Apparently it seldom if ever hibernated in the winter-oat region, and the primary reason no doubt largely lies in the fact that most of the southern oat varieties, and especially the fall-sown ones, are resistant to form 3.

Of the remaining 29 forms, forms 6, 11, 16, 20, 22, 23, 24, 25, 26, 31, and 32 were widely distributed and not limited to either the spring-sown or fall-sown areas. These forms apparently are all aggressive enough to be able to hibernate on fall-sown and volunteer oats in the South. Forms 11, 20, 24, 31, and 32 are known to hibernate in the South because they were collected in winter and early spring before *Rhamnus* plants became infected. It is probable, because of their wide distribution and limited prevalence, that most of these forms also were disseminated from naturally inoculated *Rhamnus* in the Northern States.

Forms 4, 5, 9, 12, 13, 17, 27, and 30 were predominantly southern ones, although 9, 12, and 17 occurred naturally as far north as Iowa. These three forms, however, have been observed to hibernate in the South, and it is possible that favorable winds carried urediospores north from the points of hibernation. Among this group of southern forms was form 30, the most aggressive of the 33 identified. With the exception of forms 5 and 9 all these apparently southern forms are more aggressive than form 7, which, without doubt, hibernates in the South. Because of the small number of cultures representing each of them it is impossible to state definitely that they were limited to the Southern States. If, however, these forms were distributed to any extent in the North or disseminated from *Rhamnus* their prevalence must have been very limited.

In contrast to the forms just mentioned, forms 2, 8, 10, 19, 21, 28, and 29 were northern ones. With one exception they were collected only in the Northern States and Canada, and always in the spring-oat region where the various *Rhamnus* species function as alternate hosts. One culture of form 2 was collected at State College, Miss., in 1930. Forms 29, 2, 19, and 28 were very restricted, while form 10 was comparatively highly aggressive. All of these northern forms apparently were dependent upon *Rhamnus* for their initial dissemination.

Forms 14, 15, and 18 were collected only from artificially inoculated *Rhamnus*. Since the *Rhamnus* species from which these forms were obtained are not indigenous either to the United States or Canada and were artificially inoculated it is entirely possible that these three forms were not naturally distributed in the United States or Canada.

A total of 300 cultures were collected from Mexico and the States where crown rust may hibernate on fall-sown or volunteer oats, and 172 cultures (exclusive of those collected at Ames, Iowa, from or near infected *Rhamnus*) were collected in the Northern States and Canada where crown rust does not hibernate and where the alternate host is known to function. Twenty-four forms were identified among the 300 cultures from the South, while 31 were represented in the 172 cultures from the North. It is evident from these data and from tables 7 to 13, inclusive, that the South was more evenly and thoroughly represented each year than the North. Everything being equal, therefore, a much larger proportion of forms should have been represented in the South. The obvious explanation for this apparent predominance of forms in the North is the fact that those hibernating in the South remain stable, while forms in the North may be greatly affected by hybridization and segregation.

REACTION OF OAT VARIETIES

Our knowledge of the distribution and prevalence of the 33 physiologic forms of *Puccinia coronata avenae* identified in the period 1927–32 would be of greater value if something was known of the reaction of important commercial oat varieties to these same forms. Time and labor would not permit a determination of the reaction of these varieties to all of the 33 forms. Instead, forms 1, 3, 7, 16, 17, and 18 were selected. Forms 1, 3, 7, and 16 were used because they were widely distributed and prevalent. These four forms are apparently the most important from an economic standpoint. Forms 17 and 18 were, at the time of their selection, of particular interest because of their origin. These six forms range in versatility from the very aggressive form 1 to the very restricted form 18.

The seedling reaction of 266 varieties of oats to these 6 forms was determined. The reactions of any particular variety to the 6 forms were obtained simultaneously under identical conditions. The seed of each variety came from a single panicle, was sown simultaneously, and was grown side by side in the greenhouse. The inoculations with the six forms were made simultaneously, as were also the reaction determinations. There should be no variation, therefore, in the reaction of a particular variety to the six forms because of environmental differences or variability in the genetic constitution of the seed. The number of days from inoculation until the first appearance of telia was recorded for each variety inoculated with forms 3 and 7.

The reaction of adult plants under field conditions is in many respects more important than that of seedling plants to specific physiologic forms under greenhouse conditions. Sufficient crown rust had developed in 21 of the 33 uniform nurseries listed in table 2, at the time they were inspected, to show possible significant differences in the reaction of the varieties. Besides the varieties in these 21 uniform nurseries, others were observed at Ames, Iowa, in 1929–32, and at Manhattan, Kans., in 1930.

The infection coefficients were computed for each year that a variety was observed, and if the variety was observed at a particular station more than 1 year the average infection coefficient was computed for that station. The weighted average infection coefficient was also computed for each variety. These coefficients are of limited value, because certain varieties were not grown at all stations or in all of the years; moreover, the severity of the crown-rust epiphytotics varied greatly at the several stations in the different years. The same limitations would be less applicable to a percentage of weighted mean, which might be calculated for each variety.

In table 14 are shown the infection type on seedling plants of each variety artificially inoculated with forms 1, 3, 7, 16, 17, and 18 and the average infection coefficients for adult plants of each variety growing under field conditions at various locations in the United States.

TABLE 14.—*Reaction of 266 oat varieties to 6 physiologic forms of Puccinia coronata avenae, and infection coefficients on varieties grown under field conditions for the years indicated at 12 experiment stations*

[T=trace]

Variety tested	C.I. no.	Infection type on seedling plants inoculated with physiologic form—						Infection coefficients for the years indicated on varieties grown at—																										Times observed	Weighted average of infection coefficient
								Ames, Iowa					Manhattan, Kans.				Stillwater, Okla.			Fayetteville, Ark., 1931	Denton, Tex.				Calhoun, La., 1931	State College, Miss., 1929	Knoxville, Tenn., 1929	Clemson College, S.C., 1930	Experiment, Ga.			Tifton, Ga., 1929	Gainesville, Fla., 1931		
		1	3	7	16	17	18	1929	1930	1931	1932	Average[1]	1929	1930	1931	Average[1]	1929	1931	Average[1]		1929	1930	1931	Average[1]					1928	1929	Average[1]				
Alabama Hybrid	971	4	3	4	4	4	4	40	60	40	40	45.0	30			30.0	20		20.0		20			20.0		50	0		10	2	6.0	3		12	26.25
Alber	2766	4	0	0	0	0	0		4	2	2	2.7		2		2.0		0	0	3		0	2	1.0				T—						10	1.51
Albion	729	4	4	4	4	4	4	20	20	60	36	34.0	50			50.0																		5	37.20
Alcot White	3059	4	4	4	0	4	0	25	30			27.5	50			50.0	15		15.0		35			35.0		70	0		T—	10	5.0	30		10	26.51
Algerian	3066	4	3	4	4	4	4	12	10	16	36	18.5	25			25.0	15		15.0		15			15.0		10	0		T—	T	.1	0		12	11.60
Algerian Cape	1002	4	0	4	0	1	2	T—	5	10	5	5.0	35			35.0																		5	11.02
Algerian×Calcutta	2807	4	4	4	4	4	4	20	32		45	32.3	20	5		12.5	T—		.1		T—	50		25.0		T—	0	T	5	3	4.0	T—		14	12.90
Anthony	2143	4	4	0	0	0	0	45	24	32	45	36.5	20	6	3	9.7	10	T	5.1	9	20	15	4	13.0	20	25	T—	40		T—	.1	40	4	20	18.12
Argentine	993	4	4	4	2	2	2	14	15	70	40	34.8	50			50.0																		5	37.80
Aurora	831	4	4	4	4	4	4	50	60	91	85	71.5	65			65.0																		5	70.20
Avena brevis	1783	4	0	0	4	4	4	5	2	T—	3	2.5	3	4	0	2.3	0	0	0	3	0	T	0	.1		0	0	T		0	0	0		18	1.14
A. brevis	2513	4	0	3	4	3	4		20	40	40	33.3		15	0	7.5						20		20.0	0			30						8	18.33
A. strigosa	1782	3	0	4	4	4	4	4	3	5	2	3.5	6	3	0	3.0		0	0	5		0	0	0	6			10					0	14	3.14
Do	2525	4	4	4	4	4	4		30	2	3	11.7																						3	11.70
Avoine du Maroc	1789	4	4	4	0	0	0	T—	5	30		11.7	6			6.0																		4	10.28
Awnless Culred	2676	4	4	4	4	4	4	20	20			20.0	60			60.0																		3	33.33
Awnless Monarch	1879	4	4	4	4	4	4	11	5			8.0	35			35.0																		3	17.00
Awnless Probsteier	1888	4	4	4	4	4	4	50	5			27.5	40			40.0																		3	31.67
Bathurst	1810	4	0	4	0	4	0	3	30	24	21	19.5	5	6	0	3.7	0	0	0	9	T—	T	1	.7	9	50	0	T	T—	0	.1	10	T	21	8.04
Belar	2760	3	0	4	0	4	0	2	20	15	32	17.3	8	3	0	3.7	T	0	.1	8	3	T—	T—	1.6	50	10	0	10	1	T—	.6	0	15	21	8.45
Do	2770	4	1	4	1	4	1	3	30	30	32	23.8	8	4		6.0	T—		.1		4	T—		2.1		20	0	T		T—	.1	10		14	10.11
Belyak	1630	4	4	4	4	4	4	30	40	60	40	42.5	50			50.0																		5	44.00
Bicknell	200–151	4	2	4	0	4	0	40	50	70		53.3	50			50.0																		4	52.50
Biffen White Winter	2011	4	4	4	4	4	4	20	10			15.0	50			50.0	4		4.0		25			25.0		85	0		1	T—	.6	30		10	22.51
Do	2012	4	4	4	4	4	4	35	10			22.5	50			50.0	4		4.0		30			30.0		75	0		5	T—	2.6	30		10	23.91
Black Algerian	3065	4	1	4	0	4	0	T—	5	3		2.7	3		2	2.5		0	0	4	5		T	2.6	36	32	0		5	T—	2.6	5	4	16	6.53
Do	840–1	4	1	4	0	4	0	15	T	T	7	5.6		T+		.3						T		.2											
Do	2015	4	1	4	1	4	1	3	3			3.0	30			30.0	3		3.0		10			10.0		45	0		2	T—	1.6	8	0	11	10.41

[1] Only those years for which there are reports on infection are included in the average, and where there is such a report for only one year the figure for that year is carried into the "Average" column.

TABLE 14.—*Reaction of 266 oat varieties to 6 physiologic forms of Puccinia coronata avenae, and infection coefficients on varieties grown under field conditions for the years indicated at 12 experiment stations*—Continued

[T = trace]

Variety tested	C.I. no.	Infection type on seedling plants inoculated with physiologic form—						Infection coefficients for the years indicated on varieties grown at—																										Times observed	Weighted average of infection coefficient
								Ames, Iowa					Manhattan, Kans.				Stillwater, Okla.			Fayetteville, Ark., 1931	Denton, Tex.				Calhoun, La., 1931	State College, Miss., 1929	Knoxville, Tenn., 1929	Clemson College, S.C., 1930	Experiment, Ga.			Tifton, Ga., 1929	Gainesville, Fla., 1931		
		1	3	7	16	17	18	1929	1930	1931	1932	Average	1929	1930	1931	Average	1929	1931	Average		1929	1930	1931	Average					1928	1929	Average				
Black Bell I	1767	4	4	4	4	4	4	12	40	48	----	33.3	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	37.50
Black Bell II	1308	4	4	4	4	4	4	22	16	48	----	28.7	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	34.00
Black Diamond	1878	4	3	4	4	4	4	12	50	40	60	40.5	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	42.40
Black Mesdag	1877	4	4	4	4	4	4	18	20	80	65	45.8	70	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	50.60
Black Mogul	1074	4	4	3	4	4	4	50	10	50	45	38.8	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	38.75
Black President	1992	4	3	4	4	4	4	60	60	16	----	45.3	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	46.50
Black Rival	807	4	4	4	4	4	4	40	40	60	80	55.0	60	----	----	60.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	56.00
Black Speckled	1817	4	4	4	4	4	4	36	20	----	----	28.0	55	----	----	55.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	37.00
Black Tartar	991	4	2	4	4	4	4	25	20	30	----	25.0	30	----	----	30.0	10	----	10.0	----	5	----	----	5.0	----	30	T—	----	15	5	10.0	5	----	11	15.92
Black Winter	606	4	2	4	4	4	4	25	24	30	40	29.8	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	33.80
Blue Stem	3070	4	0	4	0	4	0	20	40	----	----	30.0	40	----	----	40.0	5	----	5.0	----	20	----	----	20.0	----	55	0	----	5	T—	2.6	60	----	10	24.51
Bond	2733	I	I	0	I	I	I	----	----	0	0	0	0	----	----	0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	0
Boswell	480	4	4	4	4	4	4	40	40	----	----	40.0	70	----	----	70.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	50.00
Brunker	2054	4	4	4	4	4	4	20	8	30	24	20.5	30	----	----	30.0	5	----	5.0	----	12	----	----	12.0	----	85	0	----	----	T—	.1	40	----	11	23.10
Buddah	2799	4	4	4	4	4	4	20	20	40	40	30.0	35	15	----	25.0	8	----	8.0	----	30	T	----	15.1	----	10	----	20	T—	T—	.1	8	----	14	17.60
Burt	1436	4	4	4	4	4	4	20	30	50	54	38.5	40	----	----	40.0	5	----	5.0	----	8	----	----	8.0	----	10	0	----	----	5	5.0	5	----	11	20.64
Do	1861	4	4	4	4	4	4	10	10	30	40	22.5	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	28.00
Do	2043	4	4	4	0	4	0	25	35	50	40	37.5	45	----	----	45.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	39.00
Calcutta	994	4	4	4	4	4	4	40	50	50	28	42.0	25	----	----	25.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	38.60
Calcutta×Cape	2802	4	0	3	0	2	0	2	8	20	----	10.0	40	5	0	15.0	5	0	2.5	4	10	T	8	9.1	----	15	0	5	T—	5	2.6	5	----	18	7.35
Capa	2765	3	0	3	0	0	0	----	9	10	15	11.3	----	8	0	4.0	----	0	0	2	----	T	T—	.1	----	----	----	T—	----	----	----	----	----	10	4.44
Canadian	1625	4	3	4	4	4	4	36	70	40	----	48.7	60	----	----	60.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	51.50
Castleton Potato	1972	4	4	4	4	4	4	10	10	----	----	10.0	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	23.33
Cassel	1859–4	4	0	4	0	3	1	20	50	40	65	43.8	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	45.00
Chinese (hull-less)	1003	4	4	4	4	4	4	50	60	20	80	52.5	70	----	----	70.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	56.00
Chorol	2060	4	4	4	4	4	4	3	5	10	40	14.5	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	21.60
Coastblack	1025	4	4	4	4	4	4	23	10	----	----	16.5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	16.50
Cole	834	4	4	4	4	4	4	----	40	40	36	38.7	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	38.67
Colburt	2019	4	4	4	4	4	4	70	50	80	50	62.5	50	----	----	50.0	25	----	25.0	----	40	----	----	40.0	----	90	T—	----	20	T—	10.1	90	----	12	47.10
College Algerians	2052	4	1	4	0	4	0	25	20	6	45	24.0	30	5	4	13.0	5	T	2.6	5	5	T+	5	5.2	27	10	0	5	5	T—	2.6	5	30	21	11.31
Colorado No. 37	1640	4	4	4	4	4	4	----	5	50	50	35.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	35.00
Comewell	1317	4	4	4	4	4	4	----	20	40	45	35.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	35.00

Cornellian	1842	4	4	4	4	4	4	5	5	10	28	12.0	40	10	2	17.3	5	0	2.5	T		5	9	7.0	5			5						14	9.23
Cowra	2761	4	0	4	0	4	0	28	30	40	80	44.5	50	15	25	30.0	5	T	2.6	20	20	40	15	25.0	50	25	0	25		5	2.5	0	10	20	24.16
Culberson	273	4	4	4	4	4	4	60	60	80	85	71.3	60			60.0	30		30.0		35			35.0		95	10		15	5	10.0	10		12	45.42
Culred	189-518	4	4	4	4	4	4	25	70			47.5	60			60.0																		3	51.67
Custis	2041	4	0	4	0	0	0	60	5			32.5	55			55.0	10		10.0		8			8.0		95	0		35	5	20.0	20		10	29.30
Danish Giant	1989	4	3	4	4	4	4	12	20			16.0	45			45.0																		3	25.67
Danish Island	1684	4	4	4	4	4	4	35	30	5	44	28.5	40			40.0																		5	30.80
Do	1897	4	4	4	4	4	4	12	20			16.0	60			60.0																		3	30.67
Daubeney	1621	4	4	4	4	4	4	25	20	80	65	47.5	50			50.0																		5	48.00
Dookie No. 10	2829	4	2	4	0	4	0	40	40	45	65	47.5	45			45.0	25		25.0		30			30.0		70	T—		20	20	20.0	60		12	38.25
Diamond (hull-less)	2640	4	4	4	4	4	4			20	30	25.0																						2	25.00
Dwarf Culberson	748	4	4	4	4	4	4	60	70	40	80	62.5	50			50.0																		5	60.00
Early Blonde	3060	4	2	4	1	4	0	35	50	20	85	47.5	50			50.0	20		20.0		25			25.0		24	T—		10	10	10.0	60		12	32.43
Early Burt	3061	4	0	4	0	4	0	10	10			10.0	36			36.0	5		5.0		12			12.0		10	0		30	5	17.5	8		10	12.60
Do	2763	4	0	4	0	4	0		30	10	10	16.7		15	4	9.5		0	0	4		10	14	12.0	40			10					15	12	13.50
Early Champion	1623	4	4	4	4	0	4	50	10	20	45	31.3	50			50.0																		5	35.00
Early Joanette	1092	4	4	4	4	4	4	16	20	30	40	26.5	60			60.0																		5	33.20
Do	1393	4	4	4	4	4	4		10			10.0																						1	10.00
Early May	2828	4	0	4	0	4	0	10	5	20	21	14.0	45			45.0	5		5.0		20			20.0		10	0			5	5.0	8		11	13.54
Early Mountain	1624	4	4	4	4	4	4	30	70	40	70	52.5	50			50.0																		5	52.00
Early Ohio	3073	4	4	4	4	4	4		20	80	80	60.0																						3	60.00
Early Ripe	2803	4	1	4	1	4	0	10	10	30	50	25.0	50	10		30.0	5		5.0		20	T		10.1		15	0	5	T—	50	25.6	40		15	19.69
Echo	1892	4	4	4	4	4	4	18	15	40	45	29.5	55			55.0																		5	34.60
Edkin	2330	4	4	4	1	4	0		40	20	50	36.7																						3	36.67
Empire	1974	4	4	4	4	4	4	40	5	10	40	23.8																						4	23.75
Extra Early	3062	4	0	4	4	0	4	25	T	5	35	16.3	60			60.0																		5	25.04
Ferguson Navarro	966	4	4	4	4	3	4	60	60	30	85	58.8	60			60.0																		5	59.00
Forward	2242	4	4	4	4	4	4	40	8	10	36	23.5																						4	23.50
Fowlds (hull-less)	1996	4	4	4	4	3	4	40	5	40	36	30.3																						4	30.25
Fortune	1983	4	4	4	4	4	4	16	8	6	36	16.5	55			55.0																		5	24.20
Frazier (Tex. No. 765)	3071	4	4	4	4	4	4	20	5	40	45	27.5	50			50.0																		5	32.00
Frazier (Tex. No. 765-19)	3072	4	0	4	4	4	4	30	5	35	50	30.0	60			60.0																		5	36.00
Frazier	2381	4	4	4	4	4	4	30	40	40	40	37.5		30	20	25.0		T	.1	27		60	5	32.5				20						11	28.38
Fulghum	650-203	4	3	4	4	4	4	30	50	40		40.0	70			70.0	55		55.0		35			35.0		75	0		10	T—	5.1			10	36.51
Do	650-204	4	3	4	4	4	4	40	40	20	50	37.5	25	40		32.5	25		25.0		24	5		14.5		70	0	60	10	5	7.5	12		15	28.40
Do	2498	4	4	4	4	0	4	40	50	40		43.3	45			45.0	30		30.0		45			45.0		65	T—		15	5	10.0	15		11	31.83
Do	2499	4	4	4	4	4	4	70	80	40		63.3	80			80.0	40		40.0		40			40.0		50	T—		25	10	17.5			10	43.51
Do	2500	4	4	4	4	4	4	60	60	40		53.3	80			80.0	45		45.0		35			35.0		65	T—		40	10	25.0			10	43.51
Do	3067	4	4	4	4	4	4	35		40		37.5	50			50.0	35		35.0		25			25.0		40	0		10	30	20.0	16		10	28.10
Do	708	4	3	4	4	4	4	50	40	50	45	46.3	60			60.0																		5	49.00
Do	708-204	4	4	4	4	4	4	70	90	80		80.0	80			80.0	45		45.0		40			40.0	0	70	T—		20	5	12.5	40		12	49.10
Do	1360-217	4	4	4	4	4	4	30	50	20	45	36.3	60			60.0	35		35.0		40			40.0		55	T—		10	5	7.5	50		12	33.34
Fulmer	1859-1	4	3	4	4	4	4	10	10	10	18	12.0	28	10		19.0						0		0				5						8	11.38
Garton No. 5	1884	4	4	4	4	4	4	7	24	20	35	21.5	40			40.0																		5	25.20
Garton No. 473	1613	4	4	4	4	4	4	25	30	20	25	25.0	70			70.0																		5	34.00
Garton No. 748	1862	4	4	4	4	4	4	35	40	30	36	35.3	50			50.0																		5	38.20
Garton Gray	1864	4	3	4	4	4	4	16	20	30	36	25.5	55			55.0																		5	31.40
Garton Yellow	1612	4	4	4	4	4	4	30	20	38	36	31.0	50			50.0	20		20.0		35			35.0		80	T—		15	15	15.0	0		12	28.26
Glabrota	2630	0	0	0	4	0	0	0	0	0	T—	0	0		0	0		0	0	0		0	0	0	0			T					2	13	.18
Glen Innes	980	4	4	4	4	4	4	5	10	2	50	16.8	5	6	1	4.0	0	0	0	3	0	T	0	.1	7	50	0	0	T—	0	.1	20	0	21	7.59
Gopher	2027	4	4	4	4	4	4	25	10	20	36	22.8	60			60.0																		5	30.20
Golden	2806	3	4	4	4	4	4	25	40	16	32	28.3	30	10		20.0	25		25.0		8	55		31,5		30	0	60	10	40	25.0	3		15	25.60

TABLE 14.—*Reaction of 266 oat varieties to 6 physiologic forms of Puccinia coronata avenae, and infection coefficients on varieties grown under field conditions for the years indicated at 12 experiment stations*—Continued

[T=trace]

Variety tested	C.I. no.	Infection type on seedling plants inoculated with physiologic form—						Infection coefficients for the years indicated on varieties grown at—																								Times observed	Weighted average of infection coefficient
								Ames, Iowa					Manhattan, Kans.				Stillwater, Okla.			Fayetteville, Ark., 1931	Denton, Tex.				Calhoun, La., 1931	State College, Miss., 1929	Knoxville, Tenn., 1929	Clemson College, S.C., 1930	Experiment, Ga.			Tifton, Ga., 1929	Gainesville, Fla., 1931		
		1	3	7	16	17	18	1929	1930	1931	1932	Average	1929	1930	1931	Average	1929	1931	Average		1929	1930	1931	Average					1928	1929	Average				
Golden Drop	1890	4	3	4	4	4	4	16	30	20	30	24.0	50			50.0																5	29.20
Do	1988	4	4	3	4	4	4	25	8	50	40	30.8	35			35.0																5	31.60
Golden Giant	1606	4	4	4	4	4	4	18	10	20		16.0	50			50.0																4	24.50
Golden Sheaf	2056	4	3	4	4	4	4	20	20			20.0	25			25.0	15		15.0		20			20.0		95	0		T−	T−	0.1	30		10	22.52
Gothland	1898	4	4	4	4	4	4	21	5	60	40	31.5	55			55.0																5	36.20
Gray	2014	4	0	3	0	2	1	35	10			22.5	60	3		31.5	20		20.0		25	0		12.5		60	T+	T	1	30	15.6	5		13	19.19
Green Mountain	1892	4	4	0	1	1	0	18	15	18	36	21.8	55	15	1	25.7		0	0	T		85	5	45.0	60			60	T−	0	.1		40	16	27.22
Green Russian	1040	4	4	4	4	4	4	8	T	5	21	8.6																				4	8.55
Do	1978	4	4	4	4	4	4	18	20	5	28	17.8	60			60.0																5	26.20
Do	2342	4	4	4	4	4	4	40	20	70	40	42.5	45	15	5	21.7		0	0	7		25	5	15.0	60			3					10	14	24.64
Do	2344	4	3	4	4	4	4	1	8	24	18	12.8	2	0	0	.7		0	0	2		16	4	10.0	60			10					0	14	10.36
Do	2890	4	4	4	4	4	4			24	40	32.0			3	3.0		T	.2	T			4	4.0	48								20	8	17.43
Guyra	981	4	0	4	0	0	0	14	40	10	40	26.0	50	20		35.0	16		16.0		20	5		12.5		50	0	5	T−	5	2.6	20		15	19.67
Do	2034	4	3	3	4	3	3	7	10	32	40	22.3	50			50.0	T−		.1		8			8.0		10	0	5	T−	T−	.1	0		13	13.11
Do	2768	4	4	4	4	4	4	12	30		40	27.3	T−	20		10.1						5		5.0										6	15.33
Hajira	1001	4	4	4	4	4	4	20	20	8	36	21.0	28	32		30.0						20		20.0				15						8	22.38
Hamilton	2039	4	4	4	4	4	4	14	24	16		18.0	50			50.0	T−		.1		30			30.0		90	T−		15	T−	7.6	40		11	25.39
Hatchett	838	4	4	4	4	4	4	50	80	50	60	60.0	50			50.0																		5	58.00
Hay	1622	4	4	4	4	4	4	6	5	8	24	10.8	6	2	0	2.7						T		.2				50						9	12.65
Hawkeye (Iowa No. 102)	2464	4	4	0	0	4	0	16	20	54	32	30.5	40	12	8	20.0	5	0	2.5	10	20	10	10	13.3	70	5	0	50		10	10.0	15	20	20	20.35
Hundred Bushel (Hastings)	2797	4	0	4	0	0	0	25	10	5	7	11.8	30	5	5	13.3	T−	0	.1	10	5	T	5	5.1		5	0	35		T−	.1	T−		18	8.19
Idamine	1834	4	4	4	4	4	4	40	8	24	60	33.0																				4	33.00
Iogold	2329	4	4	4	4	4	4	25	40	30	65	40.0	50	50		50.0						20		20.0				30						8	38.75
Iogren	2024	4	4	4	4	4	4	27	30	40	18	28.8	31	12		21.5						20		20.0				50						8	28.50
Iomine	2827	4	4	4	4	4	4	36	16	40	32	31.0	40			40.0	10		10.0		20			20.0		20	T−			T−	.1	20		11	21.29
Iowa No. 67	2870	4	4	0	0	0	0	16	20	20	20	19.0																				4	19.00
Iowa No. 69	2463	4	4	0	0	0	0	24	40	50	28	35.5	45	5		25.0						40		40.0	30			40					15	10	31.70
Iowa No. 77	2813	4	4	0	0	0	0	16	50	60	25	37.8	40	20		30.0	5		5.0		20	30		25.0		8	0	30		10	10.0	15		14	23.50
Iowa No. 444	2331	4	4	4	4	4	4	18	15	10	36	19.8	31			31.0																5	22.00
Iowar	847	4	4	4	4	4	4	25	10	20	40	23.8	50			50.0																5	29.00
Irish Victor	1251	4	4	4	4	4	4	22	10	16	50	24.5	45			45.0																5	28.60

Ithacan	2141	4	4	4	4	4	4	40	15	30	45	32.5																						4	32.50
Japan	1157	4	4	4	4	4	4	50	10	50	40	37.5																						4	37.50
Do	1889	4	4	4	4	4	4	18	70	20	45	38.3	50			50.0																		5	40.60
Joanette	549	4	4	4	4	4	4		30			30.0																						1	30.00
Do	1880	4	4	4	4	4	4	16	60	12	50	34.5	50			50.0																		5	37.60
"Joanette strain"	2660	4	4	3	4	4	4		90	18	50	52.7																						3	52.67
June	1902	4	4	4	4	4	4	40	18	30	36	31.0																						4	31.00
Kanota	839	4	4	4	4	4	4	50	50	20	54	43.5	45	40	25	36.7		5	5.0	20		20	10	15.0				50						12	32.42
Kansas No. 5213-7	2823	4	0	4	0	3	0		10	18	36	21.3		50	2	26.0		T	.2	20		50	15	32.5	24			50					50	12	27.10
Kareela	2774	4								0	14	7.0			0	0																		3	4.67
Keystone	2146	4	4	4	4	4	4	40	15	10	24	22.3																						4	22.25
Kherson	459	4	4	4	4	4	4	35	30	20	40	31.3	60			60.0																		5	37.00
Do	1885	4	4	4	4	4	4	40	10			25.0																						2	25.00
Do	1905	4	4	4	4	4	4	40	10			25.0																						2	25.00
King	850	4	3	4	4	4	4	40	60			50.0	30			30.0	15		15.0		40			40.0		60	0		15	5	10.0	8		10	27.30
Lachlan	983	4	4	4	4	4	4	40	60			50.0	40			40.0	15		15.0		20			20.0		75	0		15	T	7.6	15		10	28.02
Do	2805	4	1	4	0	4	0	45	10			27.5	60	2		31.0	10		10.0		30	5		17.5		30	0	T		T—	.1	40		12	19.36
Laurel (hull-less)	2231	4	4	4	4	4	4	40	40			40.0	40			50.0	20		20.0		19			19.0		20	0		50	5	27.5	60		10	30.40
Lee	2042	4	1	4	0	4	0	60	60	40	65	56.3	60	50	40	50.0	10	0	5.0	30	20	10	25	18.3		90	T—	10	25	5	15.0	20		19	32.64
Liberty (hull-less)	845	4	4	4	4	4	4	12	10	60	60	35.5	60			60.0																		5	40.40
Lincoln	1262	4	4	4	4	4	4	18	50	30	40	34.5	45			45.0																		5	36.60
Madrid	603	4	4	4	4	4	4	40	70	50	45	51.3	60			60.0																		5	53.00
Magistral	2460	4	4	0	0	0	0	3	T	4	7	3.7	1	0	0	0.3		0	0	1		T	0	.1	6			0					0	14	1.60
Mansholt IIB	1990	4	4	4	3	4	4	20	24	20		21.3	40			40.0																		4	26.00
Mansholt III	2046	4	4	4	4	4	4	27	20			23.5	50			50.0																		3	32.33
Markton	2053	4	4	4	4	4	4	40	70	60	40	52.5	70	50	25	48.3	5		5.0	40		70	25	47.5	80			75					20	14	47.86
Marvellous	1999	4	4	4	4	4	4	16	70	50	40	44.0	60			60.0																		5	47.20
Mortgage Lifter	2804	4	4	4	4	0	4	3	3	25		10.3	6	3	8	5.7	5	0	2.5	10	T—	T	15	7.7		T—	0	0	2	T—	1.6	15		18	5.31
Miami	2245	4	4	4	4	4	4	20	18	24	36	24.5																						4	24.50
Minota	1285	4	4	4	4	4	4	20	10	16	27	18.3	45			45.0																		5	23.60
Minnesota No. 295	1290	4	4	4	4	4	4	50	10		36	32.0																						3	32.00
Mogul	1074	4	4	4	4	4	4	10	10			10.0	65			65.0																		3	26.33
Monarch	1876	4	4	4	4	4	4	10	8	2	32	13.0	50			50.0																		5	20.40
Mongolian (hull-less)	1770	4	4	4	4	4	4	60	90	50	45	61.3																						4	61.25
Mulga	2796	4	1	4	0	4	0	3	T	20	32	13.8	6	10	2	6.0	20	0	10.0	10	10	5	5	6.7		15	0	T	1	T	.6	0		19	7.35
Myall	2800	4	4	4	4	4	4	3	T	8	21	8.1	24	5	0	9.6	8	0	4.0	7	25	T	0	8.4		25	0	T	T—	T—	.1	T—		19	6.68
Nortex	2382	4	0	4	0	4	0	13	20	4	23	15.0	5	5	1	3.6	10	0	5.0	8	T—	T		2.8	45	T	0	5		T	.2	30	9	19	9.41
North Finnish	1882	4	4	4	4	4	4	10	20	60	40	32.5	45			45.0																		5	35.00
O.A.C. Fo. 72	846	4	4	4	4	4	4	18	20	20	40	24.5	60			60.0																		5	31.60
O.A.C. No 144	2476	4	4	4	4	4	4	30	40	30	36	34.0	40			40.0																		5	35.20
Odal	2047	4	4	4	4	4	4	36	10	10	45	25.3	60			60.0																		5	32.20
Old Island Black	2035	3	3	0	4	0	4	12	20	10	65	26.8	50			50.0																		5	31.40
Do	1756	4	3	2	2	2	0		20	60		40.0																						2	40.00
Oriental	1598	4	4	4	4	4	4	30	40	10	20	25.0	60			60.0																		5	32.00
Orion	2048	4	4	4	4	4	4	22	20	30	65	34.3	60			60.6																		5	39.40
Pampa	2767	3	0	3	0	0	0		16	15	36	22.3		.5	1	3.0		0	0	4		T—	2	1.5	4			0					0	12	6.93
Patterson	2147	4	4	4	4	4	4	40	18	30	32	30.0																						4	30.00
Pringle Progress	1717	4	4	4	4	4	4	40	10			25.0																						2	25.00
Probsteier	1656	4	4	4	4	4	4	9	10	20	36	18.8	60			60.0																		5	27.00
Rainbow	2345	4	4	3	4	3	4	1	3	10	25	9.8	2	3	0	1.7		0	0	5		0	5	2.5				T						12	4.52

TABLE 14.—*Reaction of 266 oat varieties to 6 physiologic forms of Puccinia coronata avenae, and infection coefficients on varieties grown under field conditions for the years indicated at 12 experiment stations*—Continued

[T = trace]

Variety tested	C.I. no.	Infection type on seeding plants inoculated with physiologic form—						Infection coefficients for the years indicated on varieties grown at—																								Times observed	Weighted average of infection coefficient
								Ames, Iowa					Manhattan, Kans.				Stillwater, Okla.			Fayetteville, Ark., 1931	Denton, Tex.				Calhoun, La., 1931	State College, Miss., 1929	Knoxville, Tenn., 1929	Clemson College, S.C., 1930	Experiment, Ga.			Tifton, Ga., 1929	Gainesville, Fla., 1931		
		1	3	7	16	17	18	1929	1930	1931	1932	Average	1929	1930	1931	Average	1929	1931	Average	1929	1930	1931	Average					1928	1929	Average				
Red Algerian	840	4	0	4	0	4	0	15	30	4	----	16.3	----	2	4	3.0	----	0	0	10	----	T	T	0.2	----	----	----	10	----	----	----	----	----	10	7.54
Do	977	4	4	1	4	4	4	T—	10	3	7	5.0	27	----	----	27.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	9.42
Do	1578	4	4	1	0	4	1	10	30	T—	40	20.0	30	3	----	16.5	----	----	----	----	----	T	----	.2	----	----	----	T	----	----	----	----	----	8	14.19
Do	1993–1	3	2	3	0	2	0	10	40	5	4	14.8	45	3	----	24.0	----	----	----	----	----	T	----	.2	----	----	----	T	----	----	----	----	----	8	13.43
Do	2033	3	3	4	4	4	3	2	20	T—	----	7.4	50	4	----	27.0	----	----	----	----	----	35	----	35.0	----	----	----	T	----	----	----	----	----	7	15.90
Do	2044	4	0	3	0	1	1	2	2	50	----	18.0	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	26.00
Do	2045	4	3	3	4	4	4	23	20	----	----	21.5	35	----	----	35.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	26.00
Red Rustproof	512	4	1	4	4	4	4	3	10	T	20	8.3	24	5	----	14.5	5	----	5.0	----	0	T	----	.1	----	8	0	T	T—	T—	0.1	5	----	15	5.39
Do	518–3	4	1	4	4	4	4	4	5	----	4	4.3	30	5	----	17.5	3	----	3.0	----	0	T	----	.1	----	10	0	0	----	T—	.1	T+	----	13	4.74
Do	844	4	0	4	0	0	0	7	1	4	4	4.0	30	----	----	30.0	5	----	5.0	----	----	----	----	----	----	5	0	----	----	----	1.0	2	----	11	5.73
Do	888	4	0	4	0	4	0	3	8	5	4	5.0	30	15	----	22.5	3	----	3.0	----	T+	T	----	.2	----	25	0	T	1	1	1.0	T+	----	15	6.40
Do	921	4	1	4	0	4	0	3	10	----	----	6.5	35	----	----	35.0	5	----	5.0	----	5	----	----	5.0	----	5	0	----	2	T—	1.1	3	----	10	6.81
Do	1008	4	2	4	4	4	4	5	20	----	----	12.5	40	----	----	40.0	10	----	10.0	----	5	----	----	5.0	----	10	0	----	2	T—	1.1	3	----	10	9.51
Do	1039	3	1	4	0	4	0	10	40	3	4	14.3	45	----	----	45.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	20.40
Do	1079	4	1	4	0	4	0	23	20	30	4	19.3	20	5	2	13.5	10	0	5.0	10	15	T+	5	6.8	18	20	0	T	T—	T—	.1	30	10	21	10.60
Do	1089	4	1	4	0	4	0	4	5	10	4	5.8	8	10	1	14.5	8	0	4.0	20	5	T	5	3.4	----	35	0	T	2	T—	1.1	8	----	19	6.60
Do	1450	4	3	4	4	4	4	50	50	----	----	50.0	50	----	----	50.0	10	----	10.0	----	35	----	----	35.0	----	48	----	----	20	5	12.5	----	----	8	33.50
Do	1571	4	0	4	0	4	0	3	10	----	----	6.5	35	----	----	35.0	15	----	15.0	----	16	----	----	16.0	----	45	T—	----	1	5	3.0	15	----	10	14.51
Do	1805	4	1	4	1	4	1	3	20	5	8	9.0	30	5	----	17.5	20	----	20.0	----	T—	T	----	.2	----	T—	0	T	----	T—	.1	8	----	14	7.12
Do	1815	4	0	4	0	4	0	3	----	4	20	9.0	----	----	3	3.0	----	0	0	4	----	4	----	4.0	6	----	----	----	----	----	----	----	10	9	6.00
Do	2808	4	1	4	0	4	0	3	20	40	5	17.0	50	5	10	32.5	----	0	0	30	----	10	15	12.5	----	----	----	T	----	----	----	----	----	12	15.68
Do	2809	4	1	4	0	4	0	T—	50	60	8	29.5	45	3	----	24.0	----	----	----	----	----	10	----	10.0	----	----	----	0	----	----	----	----	----	8	22.01
Richland	787	4	4	4	4	4	4	30	20	40	50	35.0	60	----	----	60.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	40.00
Ruakura	701	4	0	4	0	4	0	60	30	32	36	39.5	45	----	16	30.5	18	0	9.0	20	30	----	20	25.0	----	64	0	----	15	5	10.0	----	----	15	26.07
Do	1961	4	3	4	4	4	4	50	10	40	36	34.0	28	----	----	28.0	20	----	20.0	----	35	----	----	35.0	----	95	T—	----	10	5	7.5	30	----	12	29.93
Do	2025	4	1	4	1	0	0	50	60	40	36	46.5	40	30	----	35.0	30	----	30.0	----	20	85	----	52.5	90	80	T—	10	----	1	1.0	40	0	16	38.26
"Rustless selection" (Rustless)	724	4	4	4	4	4	4	45	T—	20	18	20.8	28	----	----	28.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	22.22
Schoolmarm	2057	4	4	4	4	4	4	2	5	15	14	9.0	3	3	1	2.3	----	T	.2	2	----	0	T—	.1	----	----	----	0	----	----	----	----	----	12	3.78
Scottish Chief	1699	4	3	4	4	4	4	18	5	20	27	17.5	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	24.00
Seizure	1609	4	4	4	4	4	4	25	5	20	25	18.8	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	25.00

Sidney	3063	4	1	4	1	4	1	35	40	T—	----	25.0	45	----	----	45.0	10	----	10.0	----	5	----	----	5.0	----	24	0	----	10	5	7.5	0	----	11	14.92
Silvermine	1013	4	4	4	4	4	4	25	30	20	30	26.3	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	31.00
Silvermine selection	1894	4	4	4	4	4	4	14	8	----	----	11.0	35	----	----	35.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	19.00
Sir Douglas Haig	1987	4	3	4	4	3	4	35	10	40	----	28.3	40	----	----	40.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	31.25
Sixty-Day	1887	4	4	4	4	4	4	15	15	----	----	15.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	12.50
Do	1906	4	4	4	4	4	4	10	10	50	50	30.0	60	----	----	60.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	36.00
Sparrowbill	1604	4	3	4	4	4	4	18	10	40	40	27.0	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	31.60
Standwell	1975	4	4	4	4	4	4	30	5	40	24	24.8	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	24.75
State Pride	1154	4	3	4	4	4	4	18	20	40	40	29.5	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	33.60
Sterisel (sterilis selection)	2891	4	0	4	0	----	----	----	----	5	4	4.5	----	----	0	0	----	0	0	T—	----	----	T—	.1	60	----	----	----	----	----	----	----	----	7	8	9.53
Sunrise	982	4	0	4	0	4	0	3	20	4	5	8.0	3	3	0	2.0	0	0	0	5	10	T	T—	3.4	36	40	0	0	T—	0	.1	8	10	21	7.02
Do	1799	4	0	4	0	4	0	8	16	5	16	11.3	10	8	----	9.0	10	----	10.0	----	8	0	----	4.0	----	10	0	T—	----	0	0	8	----	14	7.08
Svalöf Victory	1145	4	4	4	4	4	4	45	8	30	24	26.8	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	26.75
Swedish Select	1375	4	4	4	4	4	4	22	5	40	27	23.5	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	28.80
Tabor	1777	4	4	4	4	4	4	T—	20	40	25	21.3	40	----	----	40.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	25.02
Tartar	991	4	4	4	4	4	4	18	----	----	----	18.0	45	----	----	45.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	31.50
Tartar King	1599	4	4	4	4	4	4	40	50	40	45	43.8	60	----	----	60.0	----	----	----	----	----	----	----	--	----	----	----	----	----	----	----	----	----	5	47.00
Tech	691	4	4	4	4	4	4	15	----	20	----	17.5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	17.50
Do	947	4	4	4	4	4	4	15	40	----	----	27.5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	27.50
Terry	602	4	4	4	4	4	4	40	50	30	60	45.9	70	----	----	70.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	50.00
Texas Red	3068	4	0	4	0	4	0	T—	T	20	----	6.8	45	2	1	16.0	----	----	----	----	----	T	----	.2	----	----	----	T	----	----	----	----	----	8	8.59
Tobolsk	1709	4	4	4	4	4	4	16	30	30	45	30.3	60	----	----	60.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	36.20
Upright	2142	4	4	4	4	4	4	----	20	20	45	28.3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	28.33
Victor	803	4	4	4	4	4	4	50	40	40	40	42.5	60	----	----	60.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	46.00
Victoria	2401	1	0	0	0	0	0	0	0	T—	2	.5	T—	0	T—	.1	----	0	0	T	----	0	0	0	T	----	----	0	----	----	----	----	0	14	.19
Victoria (Scasso)	2764	1	0	0	0	0	0	----	0	1	2	1.0	----	0	2	1.0	----	0	0	2	0	0	0	0	----	----	----	0	----	----	----	----	----	11	.70
Victory	1145	4	4	4	4	4	4	18	50	30	27	31.3	45	16	----	30.5	----	----	----	----	----	20	----	20.0	----	----	----	30	----	----	----	----	----	8	29.50
Do	1985	4	4	4	4	4	4	11	30	30	27	24.5	35	4	----	19.5	----	----	----	----	----	30	----	30.0	----	----	----	60	----	----	----	----	----	8	28.38
Warrigal	2798	4	1	4	0	4	0	16	10	6	10	10.5	20	10	0	10.0	T	0	.1	4	T—	T	T—	.1	----	5	0	T	T—	T—	.1	T—	----	19	4.32
Wayne	2567	4	4	4	4	4	4	10	10	40	27	21.8	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	21.75
Wernich Golden	1746	4	4	4	4	4	4	60	3	----	----	31.5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	31.50
White Avalanche	1440	4	4	4	4	4	4	60	10	----	----	35.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	35.00
White Bonanza	1686	4	3	4	4	4	4	22	60	70	----	50.7	60	----	----	60.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	53.00
White Cross	2026	4	4	4	4	4	4	40	5	50	----	31.7	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	31.67
White Maine	1692	4	4	4	4	4	4	22	10	40	36	27.0	60	----	----	60.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	33.60
White Tartar	551	4	4	0	4	4	4	30	----	40	40	36.7	----	----	1	1.0	----	0	0	5	----	4	----	4.0	50	----	----	----	----	----	----	----	10	9	20.00
Do	1640	4	4	4	4	4	4	27	70	20	36	38.3	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	40.60
Winter Turf	1570	4	4	4	4	4	4	20	30	----	50	33.3	45	----	----	45.0	15	----	15.0	----	50	----	----	50.0	----	90	----	----	T	5	2.6	90	----	10	39.52
Wisconsin Wonder	1645	4	4	4	4	4	4	10	20	30	32	23.0	50	----	----	50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	28.40
Do	3074	4	4	4	4	4	4	50	10	24	----	28.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3	28.00
Wolverine	1591	4	4	4	4	4	4	30	8	40	32	27.5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	27.50
Worthy	1590	4	4	4	4	4	4	27	10	24	36	24.3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	27.50
Yarran	3064	4	3	4	3	3	3	25	30	80	24	39.8	64	----	----	64.0	20	----	20.0	----	45	----	----	45.0	----	30	0	----	10	20	15.0	50	----	12	33.17

A total of 266 varieties and selections of oats were inoculated in the seedling stage with physiologic forms 1, 3, 7, 16, 17, and 18. Of the 1,589 reactions observed and recorded, 1,329 were susceptible and 260 were resistant. Form 1 was by far the most virulent, only four varieties—Bond (C.I. 2733), Glabrota (C.I. 2630), Victoria (C.I. 2401), and Victoria ((Scasso) C.I. 2764)—being found resistant to it. Bond was apparently immune, showing no macroscopic evidence of infection. Glabrota was nearly immune, showing only slight chlorotic flecks. Both Victoria varieties were highly resistant, showing often only necrotic flecks, although minute uredia surrounded by heavy necrotic areas were usually present. Sixty-seven varieties were resistant to form 3, which apparently is the most common and widely distributed of the restricted forms. Eighteen varieties were resistant to form 7, a virulent and widely distributed form. Seventy, 31, and 70 varieties, respectively, were resistant to the less important forms 16, 17, and 18. Forms 16 and 18 apparently are very similar, although the differential reaction of Glabrota to these two forms was distinct and consistent.

Bond and the two Victoria varieties were the only ones resistant in the seedling stage to all 6 forms. Glabrota was resistant to all except form 16, and Alber (C.I. 2766) was resistant to all except form 1. Nineteen varieties were resistant to 4 of the 6 forms, 44 varieties were resistant to 3 forms, 7 varieties were resistant to 2 forms, and 14 varieties were resistant to 1 of the 6 forms. A total of 179 varieties were not resistant to any of the 6 forms.

The same plants observed for infection types were observed also for rapidity of telial development. An average of five plants was grown in a 3-inch clay flowerpot. These plants were not transplanted on becoming older; consequently, the development of telia on the older plants may have been hastened somewhat because of impaired growing conditions. For any particular variety, however, the plants infected with forms 3 and 7 were grown side by side under the same greenhouse conditions. There was a marked difference between forms 3 and 7 in their precocity of telial development. The average number of days following inoculation until telia appeared on those varieties infected with forms 3 and 7 was 14.4 and 31.3 days, respectively. It is obvious that the difference between these two averages is highly significant. Following the classification mentioned on page 14 these cultures representing forms 3 and 7 would be classified as groups 1 and 2, respectively.

Parker (*27*) first reported that early development of telia was positively correlated with the resistance of the host plant. This relationship was observed in the present investigation with both seedling and adult plants, although it was most pronounced with adult plants. Usually telia developed on susceptible seedling plants within a few days after they appeared on the resistant plants. Certain forms, however, developed telia only on resistant seedling plants, and other forms were not observed to produce telia on either resistant or susceptible seedling plants. A total of 266 varieties in the juvenile stage of development were inoculated with form 3; 199 were susceptible (type 3–4); 28 were resistant (type 1–2); and 39 were immune or nearly immune (type I–0). The average number of days until telia appeared on varieties susceptible and resistant to form 3 was 14.9 and 10.8, respectively, while the average number of days until telia

appeared on 247 varieties susceptible to and 3 varieties resistant to form 7 was 31.5 and 20.7, respectively.

Numerous investigators have studied the reaction of oat varieties to natural epiphytotics of crown rust under field conditions. These data are, however, of limited value because only percentages of infection were recorded, and no information is available concerning the distribution and prevalence of physiologic forms at the time the data were obtained. Levine, Stakman, and Stanton (*21*) found Green Mountain, Red Rustproof (C.I. 1815), Iowar, "Rustless selection" (Rustless), Burt (C.I. 2043), and Ruakura (C.I. 2025) to be the most resistant of 22 varieties observed throughout the United States in 1925, 1926, and 1927. In the present investigation Red Rustproof was the only variety of this group that showed high resistance, and it ranked nineteenth among the most resistant varieties. Durrell and Parker (*12*) observed the reaction of some 200 varieties of oats to field epiphytotics of crown rust in the period 1914–18. They found, as a whole, varieties belonging to *Avena byzantina* more resistant than those belonging to *A. sativa*. None of the varieties they observed showed less than 40 percent as a maximum of infection. Very few of these varieties were studied in the present investigation.

The infection coefficient, as previously described, arbitrarily expresses in a numerical manner both the type and percentage of infection combined. A variety may have a low infection coefficient either because of a resistant reaction or a low percentage of infection, or both. A low percentage of infection under field conditions in turn may be due either to external conditions, such as limited inoculum, unsuitable environmental conditions, etc., or to some functional or morphological resistance of the plant itself. There apparently is a definite relation between the age of certain varieties and the percentage of crown-rust infection under field conditions. This relation appears less evident under greenhouse conditions. Many varieties will not develop their maximum percentage of infection until they reach a certain advanced stage of development, even though inoculum and environmental conditions be optimum.

The infection coefficients recorded for Ames, Iowa, in the period 1929–32, and for Manhattan, Kans., in 1931, represent in each case the maximum for the year. Only one observation was made at the other stations. Maximum infections were not observed at Stillwater, Okla., Knoxville, Tenn., or Experiment, Ga., for any of the years indicated. The average intensity of infection was not the same at any of the stations observed. However, with the exception of Stillwater in 1931 and Knoxville in 1929 there was apparently sufficient inoculum in each nursery to expose all varieties equally.

The weighted average infection coefficients recorded in the last column of table 14 are the averages of each variety for all of the times they were observed. Unfortunately, all the varieties could not be grown at each of the stations for the years indicated. Consequently, a comparison of these average infection coefficients cannot be very specific. There is a marked tendency for the varieties to show the same relative resistance at the various stations. This probably is explained by the universal presence of form 1 and the dominance of forms 1, 3, 7, and 16. In the seedling stage many of the southern varieties, belonging mainly to *Avena byzantina*, are resistant to form 3, which is confined chiefly to the Northern States. These varieties

apparently were resistant to form 3 in the adult stage because this form was not collected from them but from varieties susceptible in their seedling stage. Moreover, certain of the northern varieties (belonging to *A. sativa* and *A. sativa orientalis*) were resistant to form 7 in the seedling stage as well as in the adult stage. In general, the infection coefficients show the effect of the resistance of the varieties to the forms present. However, the presence of an aggressive form, such as 1 or 7, makes it difficult to discern the effect of the more restricted forms.

Eighty-one of the 266 varieties given in table 14 have a weighted average infection coefficient of 20 or less and 43 have a coefficient of 10 or less. All the varieties of any apparent importance from the standpoint of crown-rust resistance, under field conditions in the United States, are included in this group of 81, and those that are outstanding for resistance are found among the 43 varieties with a coefficient of 10 or less. More than half of the varieties fall within the range of 20.01 to 40, inclusive. All these varieties as well as 36 varieties with a higher average coefficient must be considered as susceptible under field conditions in the United States, although many were doubtless resistant to one or more of the rarer forms. The distribution of the varieties in the various class ranges of weighted average infection coefficients is shown in table 15.

The ability of oat varieties to withstand epiphytotics of crown rust under field conditions is of major economic importance. The 25 varieties most outstanding in this respect are arranged in table 16 in the order of their resistance, on the basis of the weighted average infection coefficients given in table 14.

TABLE 15.—*Distribution of varieties in class ranges of weighted average infection coefficients*

Varieties (number)	Infection coefficient class range	Varieties (number)	Infection coefficient class range
43	0–10	20	40. 01– 50
38	10. 01–20	14	50. 01– 60
77	20. 01–30	1	60. 01– 70
72	30. 01–40	1	70. 01–100

The first four varieties in table 16 are very outstanding for their resistance to crown rust in both juvenile and adult stages, and they were the only varieties uniformly resistant in the juvenile stage to important forms 1, 3, and 7. In the first-leaf stage, Bond was apparently immune, or nearly immune, from these three forms, from all the forms identified in 1931, and from all except one of the forms identified in 1932. In addition to extreme resistance to crown rust, Bond has desirable agronomic characters that enhance its value for hybridization. Glabrota, belonging to *Avena strigosa*, is of no commercial importance. It is resistant to 26 of the 33 forms described in table 4 and ranks next to Bond for resistance under field conditions. Because of its chromosome number, Glabrota is of little value for hybridization. The two Victoria varieties are apparently identical, both morphologically and pathologically. These two varieties were resistant in the first-leaf stage to all the 33 forms described in table 3 and have been highly resistant under field conditions in the central and southenr portions of the United States. The history, classification, and prob-

able agronomic importance of Bond, Glabrota, and the two Victoria varieties have been reported by Murphy and Stanton (*25*) and Stanton and Murphy (*35*). In addition to their unusual resistance to crown rust these four varieties have shown apparent immunity from or extreme resistance to *Ustilago avenae* (Pers.) Jens. and *U. levis* (Kell. and Sw.) Magn. at the cooperating stations where they were grown and to artificial inoculation with both smuts at Ames, Iowa. Unfortunately, all four varieties were completely susceptible to natural epiphytotics of *Puccinia graminis avenae* whenever present.

TABLE 16.—*Average-infection coefficient of 25 oat varieties arranged in the order of their resistance to epiphytotics of Puccinia coronata avenae under field conditions; and reaction of seedling plants of these varieties to 6 physiologic forms*

Variety tested	C.I. no.	Field observations		Infection type on seedling plants inoculated with physiologic form—					
		Number	Average-infection coefficient	1	3	7	16	17	18
Bond	2733	3	0	I	I	0	I	I	I
Glabrota	2630	13	.18	0	0	0	4	0	0
Victoria	2401	14	.19	1	0	0	0	0	0
Victoria (Scasso)	2764	10	.70	1	0	0	0	0	0
Avena brevis	1783	18	1.14	4	0	0	4	4	4
Alber	2766	10	1.51	4	0	0	0	0	0
Magistral	2460	14	1.60	4	4	0	0	0	0
Avena strigosa	1782	14	3.14	3	0	4	4	4	4
Black Algerian	840–1	7	3.27	4	1	4	0	4	0
Schoolmam	2057	12	3.78	4	4	4	4	4	4
Warrigal	2798	19	4.32	4	1	4	0	4	0
Capa	2765	10	4.44	3	0	3	0	0	0
Rainbow	2345	12	4.52	4	4	3	4	3	4
Kareela	2774	3	4.67	4					
Red Rustproof	518–3	13	4.74	4	1	4	4	4	4
Mortgage Lifter	2804	18	5.31	4	4	4	4	0	4
Red Rustproof	512	15	5.39	4	1	4	4	4	4
Do	844	11	5.73	4	0	4	0	0	0
Do	1815	9	6.00	4	0	4	0	4	0
Do	888	15	6.40	4	0	4	0	4	0
Black Algerian	3065	16	6.53	4	1	4	0	4	0
Red Rustproof	1089	19	6.60	4	1	4	0	4	0
Myall	2800	19	6.68	4	4	4	4	4	4
Red Rustproof	921	10	6.81	4	1	4	0	4	0
Pampa	2767	12	6.93	3	0	3	0	0	0

Avena brevis (C.I. 1783), Alber, and Magistral have very low infection coefficients. These three varieties were resistant to important form 7 in the seedling stage. *A. brevis*, because of its chromosome number and undesirable agronomic type, is of little commercial importance. The crown-rust resistance and probable agronomic importance of Alber already have been reported by Stanton and Murphy (*35*). Magistral, belonging to *A. sativa orientalis*, has many desirable qualities in addition to resistance to crown rust. The most important of these are its white grain and extreme resistance to natural epiphytotics of *Puccinia graminis avenae* at the stations where it was grown from 1929 to 1932.

On the basis of their average infection coefficients, the remaining 18 varieties in table 16 are very important from the standpoint of resistance to natural epiphytotics of crown rust. None of these varieties was resistant in the seedling stage to forms 1 or 7. Certain of these varieties, such as Schoolmam, Rainbow, and Red Rustproof, are grown commercially in the United States. Rainbow is of particular importance because it is highly resistant to stem rust; Schoolmam also is moderately resistant. The history, classification, and

probable agronomic value of Capa (C.I. 2765), Kareela (C.I. 2774), and Pampa (C.I. 2767), have been reported by Stanton and Murphy (*35*).

The reaction of seedling plants to specific physiologic forms is more easily obtained than that of adult plants. The value of such data is limited unless it is known whether there is a relation between the age of plants and their reaction to crown rust. Johnston and Melchers (*19*) found that certain varieties of wheat were susceptible to form 9 of *Puccinia triticina* Eriks. in the seedling stage but resistant at heading time. Gassner (*16*) studied naturally infected wheat and oat plants at Estanzuela, Uruguay, in 1927. He found the younger plants of wheat most susceptible to *Puccinia triticina* but noted a loss in resistance to *P. graminis* and *P. coronata* (*P. coronifera*), respectively, as wheat and oat plants became older. Gassner observed the reaction to *P. coronata* of seven oat varieties in various stages of development. He found the greatest resistance in the uppermost leaves of the plants. Oat variety 1091–a showed a more resistant infection type in the juvenile than in the adult stage, although it was resistant in all stages of development. The major difference in reaction of juvenile and adult plants and also the variability in reaction of different parts of the plant seemed to be a difference in amount of infection rather than in infection type. Gassner's oat varieties 64–s, 64–t, and 1095–a were of the same origin and apparently identical with Capa, Victoria (C.I. 2401), and Alber, respectively.

Pure-line selections of the differential hosts and additional varieties, in three stages of development, were uniformly and simultaneously inoculated with form 1 of *Puccinia coronata avenae*. When inoculated the three stages of development were: (1) Seedling plants in first-leaf stage; (2) juvenile plants with 5 to 7 leaves; and (3) adult plants in flowering to soft-dough stages. The plants were held at a temperature of 68° to 72° F., from the time of inoculation until infection types were recorded. The results are shown in table 17.

TABLE 17.—*Reaction at different stages of development of oat varieties inoculated with form 1 of Puccinia coronata avenae*

Variety tested	C.I. no.	Stage of development				
		First leaf	Fifth to seventh leaf	Fully headed		
				Lower leaves	Upper leaves	Flag leaf
Ruakura	2025	3+	3+	3	3+	4
Green Russian	2890	4	3–4	3–	3	3+
Hawkeye	2464	3+	3+	3	3+	4
Anthony	2143	4	3–to 3+	3–	3	3+
Sunrise	982	3	3	3–	3	3+
Green Mountain	1892	3+	2+to 3	2–	2	3–
White Tartar	551	3+	3+	3	3+	3+
Red Rustproof	1815	3+	3+	3	3+	4
Sterisel	2891	3+	3	3–	3	3+
Belar	2760	3+	3–	3–	3	3+
Glabrota	2630	[1] 0 n	[2] 0 c	I	0 c	0 n
Victoria	2401	1–	0–1	0 n	1–	1
Bond	2733	0 n	0 n	I	I	I
Markton	2053	4	3+	3+	4	4+
Nortex	2382	4–	3 to 3+	3	3+	4
Alber	2766	3+	3–to 3+	2+	3–	3
Kanota	839	3+	3 to 4	3–	3	4
Richland	787	3+	3 to 4	3+	4	4+
Schoolmam	2057	3+	2+	2	2+	3–
Kareela	2774	3+	3+	3	3+	4
"Joanette strain"	2660	3	3 +to 3	2+	3	3+
Rainbow	2345	3+	2 to 3	2	3	3+

[1] n=Necrosis. [2] c=Chlorosis.

Only a slight relation was evident between the stage of development and the reaction of the varieties to form 1. Juvenile plants in the fifth- to seventh-leaf stage were slightly more resistant than seedling plants in the first-leaf stage, whereas fully-headed plants usually showed a greater variation in reaction between different portions of the same plant than was evident between plants of the same variety in different stages of development. In general, it would seem that the stage of development of an oat plant has little effect on its reaction to form 1 of crown rust, although there was apparent a slight increase of resistance in most of the varieties as they developed from the first-leaf to the fifth- to seventh-leaf stage. The dominant reaction thereafter apparently is little affected by the stage of development of the host plant.

Johnston and Melchers (*19*) observed that those wheat varieties that changed in their reaction to leaf rust as they grew older showed their highest resistance in the uppermost leaves. The data presented in table 17 indicate that the contrary is true for oats inoculated with form 1 of crown rust. Although the difference is slight it seems constant enough to be significant. Usually the infection type was uniform for an entire leaf, although leaves of adult plants sometimes showed a more susceptible reaction on the base of the leaf, as compared with the tip. No variation was observed in the infection type on different parts of the first leaf of seedling plants when inoculated with pure cultures. Seedling plants in the first-leaf stage, with the tip of the second leaf just appearing from the whorl, at the time of inoculation sometimes developed a more susceptible infection type on the tip of this second leaf than that developed on the first leaf. This variation was not often observed on the differential varieties, but such a variation was frequently observed on hybrid plants, particularly those that were heterozygous for resistance to crown rust. Hybrid plants with a mesothetic reaction to crown rust showed the greatest variation in reaction, when plants in different stages of development were infected.

These data seem to indicate that the young tissue of the oat leaf tends to be more susceptible to crown rust than the older tissue. Apparently, the reaction of the younger tissue of an adult plant tends to be similar to that of the first leaf of the seedling plant. Neither the variation due to difference in age nor that due to the portion of the plant infected appears great enough to be of any importance to the plant breeder, except when plants heterozygous for rust reaction are being studied. A variety resistant in the seedling stage to a particular physiologic form is evidently resistant in the adult stage to the same form. A variety susceptible in the seedling stage may not, however, always be equally susceptible in the adult stage. On this basis a study of the reaction of seedling plants to a specific form is of definite, although somewhat limited, value insofar as it serves as an index of the reaction of adult plants to the same form.

In addition to this apparent protoplasmic resistance characterized by necrosis and small size or absence of pustules, certain varieties apparently have what may be a functional or morphologic resistance, characterized by a low percentage or amount of infection. Adult plants of certain varieties will develop only a trace of type 4 infection, while adult plants of another variety of the same age and stage of development and under identical environmental conditions will

develop the maximum percentage of the same type of infection. Insofar as initial infection on adult plants is concerned there seems to be little, if any, correlation between the infection type and the percentage of the leaf area infected. On the other hand, there may be a striking correlation between the type and percentage of infection in secondary and later infection.

GRAMINEOUS HOST RANGE OF CERTAIN PHYSIOLOGIC FORMS

An attempt was made to determine the gramineous host range of physiologic forms 1, 3, 7, 16, 17, and 18. As many as possible of the various gramineous species that have been reported as hosts for *Puccinia coronata* were secured. The seedling reaction of each of these and other species to the above-mentioned physiologic forms was determined.

The reaction of certain species of grass to a particular physiologic form of crown rust was not nearly so constant as was that of oat varieties. Abnormal types of reaction and much variation were observed on individual plants and between different plants of the same species.

In table 18 is shown the reaction of 70 species belonging to the tribes Agrostideae, Andropogoneae, Aveneae, Chlorideae, Festuceae, Hordeae, and Phalarideae to each of the physiologic forms mentioned above.

Thirty-seven of the 70 species were, to outward appearances, immune from each of the six physiologic forms tested. Thirteen species (including 10 species of *Avena*) were susceptible to each of the six forms. Three of these (*Achyrodes aureum* (L.) Kuntze, *Anthoxanthum odoratum* L., and *Festuca octoflora* Walt.) are wild-grass species. *Anthoxanthum odoratum* and *Festuca octoflora* are of common occurrence throughout the United States, while *Achyrodes aureum* is a native of Europe and naturalized only in southern California to Texas. *Dactylis glomerata* L. was susceptible to physiologic form 7, whereas minute uredia were produced when it was inoculated with forms 1 and 3. The other forms (16, 17, and 18) produced only necrotic areas on this species. Minute uredia were produced on *Poa annua* L. by each of the six physiologic forms. *Phleum pratense* L. was somewhat variable in reaction. Uredia were produced on this species by all forms, except form 17, repeated trials with this having failed to produce any infection whatever. There was much variation in the production of chlorotic and necrotic areas on the different species. Apparently this type of infection is greatly influenced by the age and condition of the host tissue. Newly developed leaves often gave a more susceptible reaction than older ones.

The data in table 18 show that certain of the species tested differ in their reaction when inoculated with different physiologic forms. Outside of the *Avena* group, however, this evidence of physiologic specialization is insignificant. Before physiologic forms could be accurately differentiated by means of gramineous hosts other than *Avena*, it would be necessary to secure pure lines of the various species.

TABLE 18.—*Reaction of seedling plants of 70 species of grains and grasses to 6 physiologic forms of Puccinia coronata avenae*

[For explanation of symbols, see Infection Types of Crown Rust, p. 6]

Species tested	C.I. no.	Infection type on juvenile plants inoculated with physiologic form—					
		1	3	7	16	17	18
Achyrodes aureum		2-4	2-4	2-4	2-4	2-4	2-4
Agropyron caninum		I-0	I-0	I-0	I-0	I-0	I-0
Agropyron repens		I-0	I	I	I-0	I-0	I-0
Agropyron smithii		I	I	I	I	I	I
Agrostis alba		I	I	I	I	I	I
Agrostis exarata		I-0	I-0	I-0	I-0	I-0	I-0
Agrostis maritima		I	I	I	I	I	I
Agrostis palustris		I	I	I	I	I	I
Agrostis stolonifera		I	I	I	I	I	I
Agrostis thurberiana		I	I	I	I	I	I
Aira caespitosa		I	I	I	I	I	I
Alopecurus pratensis		I	I-0	I	I-0	I	I-0
Anthoxanthum aristatum		I-0	I-0	I-0	I-0	I-0	I-0
Anthoxanthum odoratum		0-4	0-3	0-4	0-3	0-3	0-3
Arrhenatherum elatius		I-0	I	I-0	I	I-0	I
Arrhenatherum elatius (Avena elatior)		I	I	I	I	I	I
Avena abyssinica	2108-2	4	4	4	4	4	4
Avena barbata	2466	4	0	4	0	4	0
Avena brevis	1783	4	0	0	4	4	4
Avena diffusa segetalis	2137	4	4	4	4	4	4
Avena diffusa volgensis	2138	4	4	4	4	4	4
Avena nuda	845	4	4	4	4	4	4
Avena nudibrevis	2465	4	4	4	4	4	4
Avena sativa	2053	4	4	4	4	4	4
Avena sativa aristata	2123	4	4	4	4	4	4
Avena sativa aurea	2127	4	4	4	4	4	4
Avena sativa mutica	2121	4	4	4	4	4	4
Avena strigosa	1782	3	0	4	4	4	4
Avena strigosa glabrescens	2630	0	0	0	4	0	I
Avena wiestii	1994	4	4	4	4	4	4
Beckmannia erucaeformis		I	I	I	I	I	I
Bromus ciliatus		I	I	I	I	I	I
Capriola dactylon		I	I	I	I	I	I
Chloris gayana		I	I	I	I	I	I
Dactylis glomerata		0-1	0-1	0-4	I-0	I-0	I-0
Elymus canadensis		I	I	I	I	I	I
Festuca confinis		I	I	I	I	I	I
Festuca duriuscula		I	I	I	I	I	I
Festuca elatior		I-0	I-0	I-0	I-0	I-0	I-0
Festuca gigantea		I	I	I	I	I	I
Festuca obtusa		I	I	I	I	I	I
Festuca octoflora		2-4	2-4	2-4	0-3	2-4	0-3
Festuca ovina		I	I	I	I	I	I
Festuca rubra		I	I	I	I	I	I
Festuca subulata		I	I	I	I	I	I
Holcus halepensis		I	I	I	I	I	I
Hordeum distichon		I	I	I	I	I	I
Hordeum jubatum		I	I	I	I	I	I
Hordeum vulgare		I	I	I	I	I	I
Lolium italicum		I	I	I	I	I	I-0
Lolium multiflorum		I	I	I	I	I	I
Lolium perenne		I	I-0	I	I	I	I-0
Lolium temulentum		I-0	I	I	I	I	I
Melica mutica		I	I	I	I	I	I-0
Notholcus lanatus		I-0	I	I	I	I	I
Phleum pratense		0-3	0-2	0-2	0-2	I-0	0-2
Poa annua		0-1	0-1	0-1	0-1	0-1	0-1
Poa arachnifera		I	I	I	I	I	I
Poa compressa		I	I	I	0	I	0
Poa nemoralis		I	I	I	I	I	I
Poa pratensis		I	I	I	I	I	I
Poa trivialis		I	I	I	I	I	I
Secale cereale		I	I	I	I	I	I
Sporobolus cryptandrus		I	I	I	I	I	I
Trisetum spicatum		I	I	I	I	I	I
Triticum aestivum (T. vulgare)		I	I	I	I	I	I
Triticum compactum		I	I	I	I	I	I
Triticum durum		I	I	I	I	I	I
Triticum monococcum		I	I	I	I	I	I
Triticum spelta		I	I	I	I	I	I

Melhus, Dietz, and Willey (*23*), using *Puccinia coronata avenae*, obtained normal infection on *Alopecurus pratensis* L. and *Arrhenatherum elatius* Beauv., while in the present investigations the maxi-

mum infection observed on these species was an 0 type. It is possible that they were using a physiologic form to which these species were particularly susceptible, or it may be that the variance in results was due to variation within the two gramineous species.

Uredia of various size were produced on the following species when inoculated with one or more of the six physiologic forms under consideration: *Achyrodes aureum*, *Anthoxanthum odoratum*, *Avena abyssinica*, *A. barbata*, *A. brevis*, *A. diffusa segetalis*, *A. diffusa volgensis*, *A. nuda*, *A. nudibrevis*, *A. sativa*, *A. sativa aristata*, *A. sativa aurea*, *A. sativa mutica*, *A. strigosa*, *A. strigosa glabrescens*, *A. wiestii*, *Dactylis glomerata*, *Festuca octoflora*, *Phleum pratense*, and *Poa annua*.

DISCUSSION AND CONCLUSIONS

Although 33 physiologic forms of *Puccinia coronata avenae* were isolated from 533 cultures collected in North America in the 6-year period 1927–32, probably many more were present. Additional differential varieties might have been selected that would have made possible the determination of other forms. Rapidity of telial development could be used as a differentiating character for the identification of additional forms. Moreover, it would conceivably be possible, with controlled environmental conditions, to subdivide certain of the forms already described by employing more refined but constant differences in infection types. It is also obvious that the isolation of a larger number of cultures would have disclosed additional more or less rare forms. Other characters doubtless will be discovered that may be employed for differentiating physiologic forms of crown rust. There is, however, no present apparent need for a finer differentiation than that employed to describe the 33 forms herein reported. On the other hand, it would be possible to combine the forms described into groups of more or less similar forms.

It is evident from the data obtained during this investigation that the physiologic-form flora of North America is not fixed. Forms 1, 3, and 7 were present each year and other more or less rare forms probably were present throughout the period of the investigation; but, in general, there was considerable variation in the occurrence and distribution of the forms from year to year. The constant appearance of forms 1 and 7 is explained in part, at least, by their regular hibernation in the winter-oat region. The fact that form 3 was consistently disseminated by naturally inoculated *Rhamnus cathartica* also explains its constant appearance and indicates that it probably is a homozygous form. Similarly, form 1 was consistently disseminated from naturally inoculated *R. lanceolata*. When these two forms, however, were used to inoculate other species of *Rhamnus* additional forms appeared in the aecial stage. Possibly *R. cathartica* and *R. lanceolata* have a selective or differential effect.

The year-to-year variation in the physiologic-form flora is no doubt largely due to hybridization and segregation on the alternate host. Most of the forms studied apparently were sufficiently aggressive to allow hibernation on fall-sown and volunteer oats in the winter-oat region, but only a few forms appeared to hibernate successfully. It is probable that forms vary in their reaction to environmental conditions when hibernating and that certain forms survive where others cannot. Mutation also may be a source of origin for new forms, but such occurrences are probably rare.

The methods of origin of new and reappearance of old forms are doubtless as old as the species itself, and it would seem that the physiologic-form flora of a particular region would become more or less fixed. However, with varying environmental conditions, introduction of new *Rhamnus* species, and constant development and introduction of new and elimination of old oat varieties, it is evident that there is much to disturb the stability of the physiologic-form complex.

In Europe, Klebahn (*20*) first divided *Puccinia coronata* Corda into two species, *P. coronata* (Corda) Kleb. and *P. coronifera* Kleb. He differentiated these two species mainly on the basis of their ability to infect *Rhamnus frangula* and *R. cathartica*, respectively. In North America Melhus, Dietz, and Willey (*23*) and Fraser and Ledingham (*14*) have shown that certain species of *Rhamnus* act as differential hosts for the parasitic races of *P. coronata* Corda. It is apparent from data secured in the present investigation that certain species of *Rhamnus* also may act as differential hosts for physiologic forms of the parasitic race *P. coronata avenae*. Frenzel (*15*) and other German investigators recognize Klebahn's classification and designate crown rust of oats as *P. coronifera* Kleb. Frenzel (*15*), however, observed unusually heavy infection on *R. cathartica* in Germany in 1929 and was unable to secure uredia on oats inoculated with the aeciospores from *R. cathartica*, although he did obtain uredia on various grass species. With these data at hand it seems only logical to retain all parasitic races and physiologic forms of crown rust of oats under the one morphologic species *P. coronata* Corda. Physiologic specialization in the species is highly developed and is evident on both the alternate and gramineous hosts. Ruakura was resistant to all except 1 of Frenzel's (*15*) 33 forms, whereas in the present investigation this same variety was resistant to 16 of the 33 forms described. It is, therefore, evident that the physiologic-form floras of Germany and North America are radically different. There is, however, no apparent justification for the designation of crown rust of oats as different species in the two countries.

Resistance to crown rust among oat varieties was not common. None of the commercial oat varieties studied was outstanding for resistance to crown rust in either seedling or adult-plant stages of development. The varieties belonging to *Avena byzantina* were more resistant as a group than those belonging to *A. sativa* or *A. sativa orientalis*. Highly resistant varieties were, however, present in each species, such as Bond, Victoria (C.I. no. 2401), and Magistral, belonging to *A. byzantina*, *A. sativa*, and *A. sativa orientalis*, respectively. Bond, Victoria (C.I. nos. 2401 and 2764), and Glabrota were outstanding for their seedling and adult resistance. The two Victoria varieties showed no susceptibility in any of the tests, and Bond was susceptible only to form 33. Fortunately, these varieties also showed considerable resistance to *Ustilago avenae* and *U. levis*. Magistral and Rainbow were resistant to crown rust under field conditions and, in addition, were highly resistant to stem rust in all of the tests. These two were the only varieties that notably were resistant to both rusts under field conditions. Desirable agronomic varieties resistant to stem rust and smut have already been developed. Appropriate crosses between these and the above-mentioned crown-rust-resistant varieties have been made, and it is hoped that by back crossing and careful selection under epiphytotic conditions desirable

high-yielding agronomic strains resistant to all four of these major oat diseases will be developed.

SUMMARY

All the physiologic forms of *Puccinia coronata avenae* yet described in North America are compared and given a standardized numerical designation.

Thirty-three physiologic forms, occurring in North America in the 6-year period 1927–32, are described.

Physiologic forms differ not only in pathogenicity on oat varieties but also in rapidity of telial development. Certain forms could be subdivided on this basis. Restricted forms tend to develop teliospores more rapidly than aggressive forms. Telia usually appeared on resistant varieties a few days earlier than on susceptible ones.

The 33 forms varied in versatility from the very aggressive forms 1 and 30 to the very restricted forms 2 and 29.

Fourteen forms were collected from naturally and artificially inoculated *Rhamnus* species. Certain species tend to harbor specific forms.

Form 2 evidently is heterozygous. Five additional forms were isolated among aecial collections from species of *Rhamnus* inoculated with form 2. New forms apparently originate by hybridization and segregation on the alternate host.

The reaction of the differential varieties, and of Victoria, Bond, and Markton, when held at 55°, 65°, 75°, and 85° F., to forms 1 and 7 was determined. The reaction of these varieties to form 1 was not greatly affected by temperature, but the effect of temperature on their reaction to form 7 was striking. At 85° form 7 could hardly be distinguished from form 1. Certain varieties were resistant at low and susceptible at high temperatures, while at an intermediate temperature they developed a mesothetic reaction. Other varieties did not change from resistant to susceptible but exhibited a decrease in resistance or an increase in susceptibility as the temperature became higher.

The distribution and prevalence of the 33 forms in 1927–32 are reported. Forms 1, 3, and 7 were present each year. Forms 1 and 7, and a number of less important forms, hibernate on fall-sown and volunteer oats in the winter-oat region. Other forms apparently are entirely dependent upon the alternate host for initial dissemination in the spring. Form 7 apparently is dependent upon hibernation for survival. Forms 1 and 7 were the most widely distributed and most commonly prevalent forms.

The seedling reaction of 266 oat varieties to forms 1, 3, 7, 16, 17, and 18 and the adult reaction of these same varieties to natural epiphytotics of crown rust at various locations in the central and southern portions of the United States are presented. Form 1 was the most aggressive of the six forms studied, only 4 varieties—Bond, Glabrota, Victoria (C.I. 2401), and Victoria ((Scasso) C.I. 2764)—being resistant to it in the seedling stage. Bond and the two Victorias were the only varieties resistant to all six forms.

Certain oat varieties were slightly more resistant to form 1 in the juvenile (fifth- to seventh-leaf stage) than in the seedling (first-leaf stage). Adult plants exhibited a variation in reaction on different portions of an individual plant, usually equal to that found on plants of the same variety in the different stages of development. Whenever differences in reaction on an individual plant were evident, the

younger tissues appeared most susceptible and the older tissues most resistant. This difference, however, with the exception of plants heterozygous for reaction to crown rust, was always meager.

The reaction of 70 gramineous species to 6 forms was characterized by almost uniform immunity or extreme resistance. *Achyrodes aureum, Anthoxanthum odoratum, Dactylis glomerata, Festuca octoflora, Phleum pratense, Poa annua,* and 14 species of *Avena* developed uredia when inoculated with 1 or more of the 6 forms. There was evidence of slight differential reaction on *Anthoxanthum odoratum, D. glomerata, F. octoflora,* and *Phleum pratense.*

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STUDIES OF THE IRRIGATION OF PEAR ORCHARDS ON HEAVY SOIL NEAR MEDFORD, OREG.[1]

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INTRODUCTION

The practice of irrigating the pear orchards of the Rogue River Valley, wherever water for irrigation is available, has become almost universal in recent years. Commercial orchard experience has demonstrated that irrigation is of value in the production of satisfactory yields of fruit of marketable size, but no definite information has been available to the orchardists as to the proper frequency, amount, or time of application of irrigation water.

Within the past few years the competition of other districts in the somewhat limited winter-pear market has made it more and more evident that the pear industry of the Rogue River Valley can survive only by meeting such districts in a price competition. It has been shown by Besse, Brown, and Wilcox (*2*)[3] in a study of production costs, that "yield is the dominant factor in reducing cost per box."

[1] This bulletin is a report of investigations carried on under a cooperative agreement between the Bureaus of Agricultural Engineering and Plant Industry, U.S. Department of Agriculture and the Oregon Agricultural Experiment Station.

[2] Sincere thanks are due F. C. Reimer, superintendent of the Southern Oregon Branch Experiment Station, and to C. L. Powell, formerly junior physiologist, Bureau of Plant Industry, for studies of the dessert and keeping qualities of the pears grown in these experiments. The cooperators, Chester Fitch, owner of the Fitch orchard, and Wood & Riddle, of the Klamath orchard, extended every facility to further the progress of the experiments.

[3] Italic numbers in parentheses refer to Literature Cited, p. 33.

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Recent experiments show that the amount of irrigation has a marked effect on both the size and the total yield of fruit.

The water supply in the Medford district is distinctly limited, and it is highly desirable that information as to the best use of this limited supply be available. In some years the supply is far below normal, and the small quantity available should be applied at times when it will be most useful. In considering the possibility of increasing the water supply by expensive works, definite information as to the value of heavier irrigation in increasing the yield of fruit is essential.

FORMER IRRIGATION STUDIES

Irrigation investigations have been conducted in the Rogue River Valley at various times. The early workers (*4*, *5*, *8*) were interested primarily from the engineering point of view and obtained information from studies of soil and climatic conditions and from observation of results secured by pioneer irrigation farmers. They were convinced that irrigation would undoubtedly prove profitable, if not essential, to successful farming and fruit growing. The first extensive experimental investigations of the results of irrigation on the yield of fruit were conducted during the years 1907 to 1911, inclusive, by Lewis, Kraus, and Rees (*3*). Their endorsement of irrigation is somewhat qualified. Among their conclusions regarding the effects of irrigation are the following:

> Irrigation aided in giving a larger percentage of fruit that came up to good packing size. In several cases it was found that irrigation had an influence on the succeeding crop. The irrigated trees had more numerous and stronger fruit buds. Some of the heavier types (of soil) such as the stickies or adobes have shown best results under cultivation without the use of water. The soils of medium texture have shown a direct benefit from light irrigation . . . . When Bartlett pear trees from 7 to 8 years of age which are in good vigor and planted on strong soils are irrigated, the trees have a tendency to become more susceptible to disease. The use of an excessive amount of cold water in the irrigation of pear trees on sticky soil is a questionable practice. It did not increase the size or quality and the result on the tree was detrimental rather than beneficial. Experiments were conducted with Winter Nelis, d'Anjou and Bartlett pear trees 18 years of age located on a heavy type of soil of varying depth and quality. The orchard was so divided that the poorer soils received irrigation while the better soils were given intensive cultivation but no irrigation. The results were in favor of the nonirrigated plot, showing that irrigation cannot be made to make up for poor quality of soil.

Their conclusions as to the value of irrigation on the sticky soil appear to be based on the results obtained in the orchard described in the last conclusion just quoted. It is possible that if the soil had been equally good on the two plots their conclusions as to the value of irrigation would have been reversed.

Studies on the rate of penetration of irrigation water were carried on by Hartman[4] in 1925 and McCormick[5] in 1926. Both found that in the heavy soils it was difficult to secure proper penetration of irrigation water into the deeper subsoil by the methods of irrigation in common use. In neither case did the investigations include records of either the yield or the growth of fruit. McCormick noted in respect to one plot that by July 15, 30 days after the second and last irrigation, the fruit on the trees near the head ditch, which had

[4] Hartman, C., Jr. Unpublished report of cooperative irrigation studies. U.S. Dept. Agr., Bur. Pub. Roads, and Oreg. Agr. Expt. Sta. 1925.

[5] McCormick, J. H. Unpublished report of cooperative irrigation studies. U.S. Dept. Agr., Bur. Pub. Roads, and Oreg. Agr. Expt. Sta. 1926.

received the larger quantity of irrigation water, was growing much more rapidly than the fruit on trees farther from the ditch. He concluded that ". . . three 4-inch irrigations would be none too much on this soil type during such a hot, dry season as 1926." He also found that a cover crop of vetch "seemed to aid penetration and absorption of water."

NEW IRRIGATION STUDIES

The series of irrigation studies described in this report covers the growing seasons of 1930, 1931, and 1932. It was started in the spring of 1930 under a cooperative agreement between the Bureau of Agricultural Engineering, United States Department of Agriculture, and the Oregon Agricultural Experiment Station and was carried on by them jointly during the seasons of 1930 and 1931. The Bureau of Plant Industry, United States Department of Agriculture, also was a party to the cooperative agreement in 1932.

The investigations covering the 3-year period were made in two commercial pear orchards belonging respectively to Chester Fitch and the Palmer Corporation of which David Wood is manager, the owners assisting whole-heartedly in the studies. Work in these two orchards was discontinued in the fall of 1932 and as information believed to be of material value to the pear-growing industry has been obtained it is believed desirable to report the results at this time, although more detailed studies were initiated in 1932 at the Medford Experiment Station. It is planned to carry on these studies under the triparty cooperative plan for a number of years and to publish the results from time to time.

THE MEDFORD DISTRICT

The Medford district is situated in the upper Rogue River Valley in Jackson County, southwestern Oregon. The principal agricultural lands of the area lie on the floor of the valley of Bear Creek, a tributary of Rogue River, and on the low foothills bordering that valley.

The climate is semiarid, with a comparatively long growing season and with sunshine nearly every day during the summer months. Precipitation data for Medford for the past 4 years, with normals as reported by the United States Weather Bureau, are shown in table 1.

TABLE 1.—*Monthly and annual precipitation at Medford, Oreg., 1929–32* [1]

Month	Normal	1929	1930	1931	1932
	Inches	*Inches*	*Inches*	*Inches*	*Inches*
January	2.78	1.47	2.45	1.39	2.03
February	2.42	.24	1.59	1.06	.26
March	1.70	.93	.49	1.16	2.43
April	1.25	1.54	1.09	1.23	2.44
May	1.21	.41	.82	.23	3.05
June	.73	2.54	.12	3.49	1.77
July	.36	.00	T	.00	.04
August	.24	.00	T	T	.12
September	.52	T	1.58	1.23	.00
October	1.34	1.14	.30	1.74	.70
November	2.48	.02	2.17	3.12	3.04
December	3.11	6.45	1.06	4.21	2.93
Annual	18.14	14.74	11.67	18.86	19.41

[1] From U.S. Weather Bureau Records.

The soils of the Medford district are extremely varied, having a very wide range in texture and other characteristics. Locally the soils are grouped in three classes, designated "granite", "free", and "sticky." The "granite" soils, as the name indicates, are derived from disintegrated granite and have a coarse porous surface soil, often underlaid at depths of 2 or 3 feet with practically impervious subsoil. The "free" soils, which occur chiefly along the stream beds, are easily worked and are alluvial deposits of medium to coarse texture. The "sticky" soils are heavy clays, clay loams, silty clay loams, and clay adobes, which are but slightly pervious to water and are difficult to work. When the soil survey of this area was made in 1911 (*6*), 43 soil types were described and mapped.

A detailed survey of the orchards in the area west of Bear Creek and south of Rogue River was made in 1930. The map showing the results of this survey was compared with the soil survey map and the areas of pear orchards on the various classes of soils were determined. It was found that of the 7,360 acres of pear orchards in the area, 1,375 acres were on light soils (sands and sandy loams), 2,655 acres were on medium soils (loams and gravelly loams), and 3,330 acres were on heavy soils (clay loams, silty clay loams, clays, and clay adobes). It is estimated that two-thirds of the 4,000 acres of pear orchards not included in this survey are on heavy soils. It appears, therefore, that about one-half of the pear orchards of the valley are on heavy soils. This estimate agrees with the earlier study made by Besse, Brown, and Wilcox (*2*) which showed that in 1924 to 1927 48.7 percent of the bearing pear trees were on heavy soil.

As is usual in irrigation practice, both the heavy and the light soils of this area cause trouble in irrigation. The application of water to the soils of medium texture presents no especial difficulties. The experimental results by Hartman [6] and McCormick [7] and the experience of the orchardists indicate clearly that more difficulty is met in the irrigation of the heavy soils than with the lighter soils.

As stated above, approximately half of the acreage in pear orchards has heavy soil. A much smaller proportion has very light soil. It appears, moreover, that the orchards on the heavier soils bear more heavily than those on the light soils. Therefore, the proportion of the crop produced on the "sticky" soils is even larger than the survey figures of acreage indicate. For these reasons it was decided that the first experimental work should be done on heavy soil.

ORCHARDS STUDIED

Two orchards were selected for cooperative investigations. In selecting these orchards the following factors were considered: (1) Availability of irrigation water, (2) uniformity of trees in the portion of the orchard available for plots, (3) willingness of the orchardist to cooperate, (4) uniformity of soil type, (5) importance of the variety of pears in the valley crop, (6) depth to the water table, and (7) typicalness and suitability of the soil type.

The Fitch orchard is located on the lower slope of the hills bordering the southeastern side of the Bear Creek Valley. The Klamath orchard, owned by the Palmer Corporation, is on the floor of the

[6] HARTMAN, C., Jr. See footnote 3.
[7] MCCORMICK, J. H. See footnote 4.

valley not far from the same hills, the former about 3 miles and the latter about 1½ miles south of the city of Medford.

The Fitch orchard soil is classed (*6*) as Meyer silty clay loam. It is very sticky when wet, hard to work, and but slightly pervious to water. The trees are Bartlett pears in full bearing. The orchard has been well cared for and, as far as is known, all of that portion used in these experiments had been uniformly handled up to the beginning of these studies.

The soil of the Klamath orchard is classed (*6*) as Meyer clay adobe and is uniform throughout the area covered by the plots. This soil is similar to that of the Fitch orchard in that it is but slightly pervious, sticky when wet, and hard to work. The trees are Anjou pear trees in full bearing. This orchard also has been well and uniformly cared for in the past.

The soils of both orchards lie on somewhat disintegrated sandstone or shale from 3 to 6 feet beneath the surface. The water table is below the surface of the rock at all times, except occasionally just after a heavy irrigation, when it may rise above the rock surface for a few days.

PLAN OF COOPERATIVE EXPERIMENTS

Experience has shown that experiments intended to determine the proper time and quantity of irrigation must be based on the moisture content actually present in the soil. Experiments based solely on different numbers of irrigations, different quantities of water applied in a fixed number of irrigations, or any combination of these two factors do not yield satisfactory results. In these studies the different irrigation treatments were based on the soil-moisture content of the upper 3 feet of soil. This depth was chosen, more or less arbitrarily, because it was thought that most of the roots would be found within that zone. Later investigations [8] have confirmed that opinion.

Definitions of certain terms used in this report, given from the standpoint of field practice and for farmers rather than for laboratory practice, are as follows:

"Field capacity" is the quantity of water retained, following plentiful precipitation or irrigation, by one or all of the upper 3 feet of soil, as designated, after the surface has been sufficiently drained to permit the taking of samples under field conditions.

This may be from 1 or 2 days for sandy loams to much longer periods for clay soils, the length of the period varying both with nature of soil and climatic conditions. It relates to the quantity of water normally stored in the soil prior to material reduction thereof by plant transpiration, but is not to be confused with the gross quantity held by the soil when saturated.

"Permanent wilting percentage" refers to the quantity of water remaining in the soil at the stage when the root hairs of the plant can no longer obtain enough moisture to prevent permanent wilting.

"Available water capacity" or "available moisture capacity" is the difference between field capacity and permanent wilting percentage, and relates to the quantity of water that the plant can normally take from the soil.

Four similar plots having 5 or 6 suitable trees in inner rows were selected in uniform orchards growing on uniform soil. Soil moisture was to be maintained at high, medium, and low states in three of the

[8] ALDRICH, W. W., WORK, R. A., and LEWIS, M. R. PEAR ROOT CONCENTRATION IN RELATION TO SOIL MOISTURE EXTRACTION IN HEAVY CLAY SOIL. Unpublished manuscript.

plots, and the fourth plot was to be treated as in general commercial practice. It has been shown by Veihmeyer and Hendrickson (7) that it is impossible to maintain the moisture in the root zone of growing crops at any definite moisture content below the field capacity and above the permanent wilting percentage. The plan adopted called for permitting a definite portion of the available soil moisture—that held between the field capacity and the permanent wilting percentage—to be withdrawn from the soil of each plot before applying water. At each irrigation a measured quantity of water, calculated to be sufficient to bring the moisture content of the whole soil mass up to the field capacity was applied. On plot E the limit below which the moisture content was not allowed to drop was 80 percent of the available moisture capacity; on plot D, 50 percent, and on plot B, 20 percent. Plot C, the check plot, was irrigated at the same time and with the same quantity of water as the owner used on the portion of the orchard not included in the experiments. Since the permanent wilting percentage of these soils was not known when these experiments were initiated it was assumed to be one-half of the field capacity.

The crop from each plot was harvested separately and records were kept of the quantities of the different sizes. Samples of fruit from each plot were examined for dessert quality at the time of picking, and other samples were stored for different periods and the storage and dessert qualities were determined.

PLOT LAYOUT

It was realized that duplication of plots would be desirable. However, funds and personnel have been distinctly limited throughout these studies and the plan adopted with single, fairly large plots has certain advantages. The labor involved in measuring and applying irrigation water was reduced to a minimum, it was possible to sample the soil intensively, and, perhaps most important of all, the area required for the experimental work was small enough to assure reasonable uniformity of trees and soil and not unduly burden the cooperating orchardists. Since there appeared to be some danger that horizontal percolation of irrigation water and distribution of the roots of individual trees would permit the irrigation treatment applied to one row of trees to affect trees in more than one adjoining row it was thought desirable to provide double guard rows between plots, where feasible. Subsequent experience confirmed that opinion. Figure 1 shows the arrangement of the plots in the two orchards. The locations of the record trees (those from which yield and other records were obtained), the soil sample holes, the irrigation flumes, and the direction of the slope of the land and of the irrigation furrows, are shown on this figure.

SOIL MOISTURE

As was the case in determining the number of plots to be used, financial limitations precluded the use of either as many samples for each determination of the moisture content of the soil of a plot or as frequent sampling as seemed desirable. The plan adopted was to sample each plot before and after each irrigation and at intervals of 1 to 2 weeks at other times. Five holes were used in each plot for each determination. These holes were so located that all parts of the root zones of the individual trees and all parts of the plot were rep-

resented. Samples were taken in 1-foot increments with the King soil tube.

During 1930 and 1931 the moisture content was determined separately for each foot of each hole. During the 1932 season the corresponding foot samples for all five holes in each plot were placed in a single large can and the moisture content of the composite sample determined. Moisture-content determinations were made by weighing and drying the whole sample as it came from the field. Samples were dried for approximately 48 hours at 110° C., a number of trials having shown that drying for that length of time resulted in constant weight. Samples were taken to bedrock in all cases.

Large samples for use in determining permanent wilting percentages of the soil were secured with a post-hole auger at each sampling point. These constants were determined separately on each foot of soil from

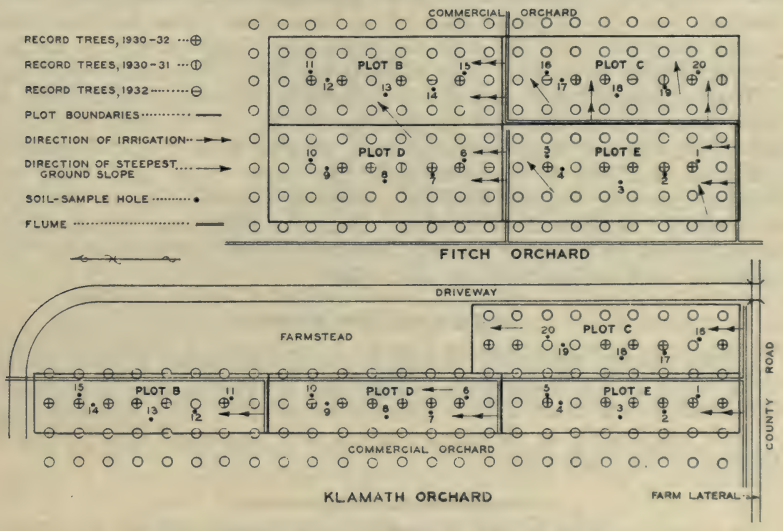

FIGURE 1.—Experimental plots in Fitch and Klamath orchards.

each hole. By making both moisture content and soil moisture constant determinations separately for the individual samples, a better picture of the variation in conditions throughout the plots is secured.

IRRIGATION

Irrigation water for the Fitch orchard is secured from the Talent Irrigation District. The Medford Irrigation District serves the Klamath orchard. Irrigation water was available for these experiments throughout each season except during the late summer of 1931, when no water was available for the Fitch orchard after July 1 and none for the Klamath orchard after the middle of July.

Water was applied in both orchards by the furrow method. All water applied was measured either by means of adjustable miner's-inch boxes under a constant head of 4 inches or over a 90° triangular notch weir. No surface waste was permitted from the plots except in one or two instances when small quantities of water escaped by accident.

CROP PRODUCTION

The fruit from each record tree was picked separately (data not presented) and the yield in lug boxes was recorded. The fruit from all of the record trees of each plot was then combined in one lot and run through grading machines in the packing houses. A record was kept of the number of pounds of each commercial size of fruit from each plot, as well as of the weight of culls.

Samples of the fruit from each plot were saved for study of the dessert and keeping quality of the fruit each season.

TREE RESPONSES

In February 1932 the junior writer became actively associated in these studies, and during the 1932 season it was possible to make additional observations of the responses of the trees to different conditions of soil moisture. These studies have included the measurement of the circumference of 15 pears on each of three trees in each plot at semi-weekly intervals from the time the pears were large enough to measure almost to picking time. The same pears were measured every time.

The lengths of spur and shoot growth for the seasons of 1931 and 1932 were determined by measuring 50 to 100 typical spurs and shoots on each of three trees in each plot in March and November.

Bloom and set of blossom data for 1929, 1930, and 1931 were obtained during March 1932 by a careful examination of 120 spurs on each of five trees in each plot. Data for 1932 were obtained from actual count of growing points, blossoms, and fruits on three small limbs on each of five trees in each plot.

DATA AND DISCUSSION

It has seemed desirable to follow the presentation of each section of the data by its discussion, rather than to present the whole mass of data and follow that with a discussion of all of it. Certain types of data applicable to all three seasons are presented apart from the discussion for each year.

SOIL-MOISTURE CONSTANTS

The values of the field capacity, permanent wilting percentage, and available water capacity for the soil of these plots are shown in table 2. The ratios between these constants and a discussion of their determination and meaning are given by Work and Lewis. [9]

TABLE 2.—*Field capacity, permanent wilting percentage, and available water capacity of the soil at different depths on each plot of the Fitch and Klamath orchards*

Plot	0–1 foot depth			1–2 feet depth		
	Field capacity	Permanent wilting percentage	Available water capacity	Field capacity	Permanent wilting percentage	Available water capacity
Fitch orchard:						
E	25.0±0.09	13.8±0.20	11.2	26.3±0.16	14.7±0.17	11.6
D	25.2± .23	12.9± .20	12.3	27.2± .15	15.7± .23	11.5
B	24.8± .14	13.2± .19	11.6	28.6± .14	16.3± .16	12.3
C	23.8± .20	16.3± .20	10.5	27.5± .14	15.9± .18	11.6
Klamath orchard:						
E	29.7± .14	16.0± .23	13.7	28.7± .04	17.0± .25	11.7
D	29.9± .19	16.8± .22	13.1	28.0± .06	17.1± .19	10.9
B	27.0± .24	15.6± .23	11.4	27.1± .13	17.7± .19	9.3
C	28.2± .27	14.7± .10	13.5	28.2± .09	16.9± .25	11.3

[9] WORK, R. A., and LEWIS, M. R. MOISTURE EQUIVALENT, FIELD CAPACITY AND WILTING POINT AND THEIR RATIOS IN A HEAVY SOIL. Unpublished work.

TABLE 2.—*Field capacity, permanent wilting percentage, and available water capacity of the soil at different depths on each plot of the Fitch and Klamath orchards*—Con.

Plot	2–3 feet depth			0–3 feet depth		
	Field capacity	Permanent wilting percentage	Available water capacity	Field capacity	Permanent wilting percentage	Available water capacity
Fitch orchard:						
E	28.6±0.18	17.1±0.40	11.5	26.6±0.09	15.2±0.16	11.4
D	28.2± .21	17.2± .30	11.0	26.9± .12	15.3± .14	11.6
B	27.5± .24	17.5± .21	10.0	27.0± .10	15.7± .11	11.3
C	29.6± .12	17.8± .21	11.8	27.0± .09	15.7± .11	11.3
Klamath orchard:						
E	27.4± .12	16.9± .17	10.5	28.6± .06	16.6± .12	12.0
D	26.6± .26	18.0± .27	8.6	28.2± .11	17.3± .13	10.9
B	26.1± .13	15.3± .28	10.8	26.7± .10	16.2± .14	10.5
C	29.0± .11	16.6± .20	12.4	28.5± .11	16.1± .11	12.4

These data indicate that in the two orchards the average capacity for moisture in available form in the upper 3 feet of the soil is about the same, but that at certain depths in each orchard the available capacity may be as much as one fifth larger in one plot than it is in another. The data also show marked differences in the field capacities and permanent wilting percentages of the soil at different depths in each orchard. In the Fitch orchard both of these values increase with greater depth, while the reverse is true of the field capacity in the Klamath orchard. In the latter orchard the first foot has the highest capacity for available moisture. This variation in the field capacity and permanent wilting percentage for different depths in the soil made it necessary to adopt some method of plotting soil-moisture conditions that would permit a more direct comparison of the relative availability of moisture at different depths and between the two orchards.

The plan adopted shows the moisture content of the soil as a percentage of the available water capacity. In other words, the moisture present at the field capacity is taken as 100 percent and the moisture present at the permanent wilting percentage is taken as zero. The moisture content of the soil at any time may then be expressed as the available moisture present in terms of the percentage of the capacity of the particular soil zone to hold available moisture.

RATE OF PENETRATION OF IRRIGATION WATER

The rate of penetration of water into this soil is very slow and this constitutes one of the difficulties in practical orchard management. It was found that the rate of penetration was as good with shallow as with deep furrows. Furthermore, in making shallow furrows fewer roots were cut and less power was required than for making deeper furrows.

In the first irrigations an attempt was made to secure uniform absorption by turning a comparatively large stream down each furrow at the beginning of the irrigation and as soon as this stream reached the end of the furrow to reduce it to the amount that would just maintain a trickle of water to the end of the furrow without causing

any run-off from the lower end of the plot. This method was found to be unsatisfactory, probably because the initial large stream of water flowing in the furrow silted over the absorbing area of the furrow, and

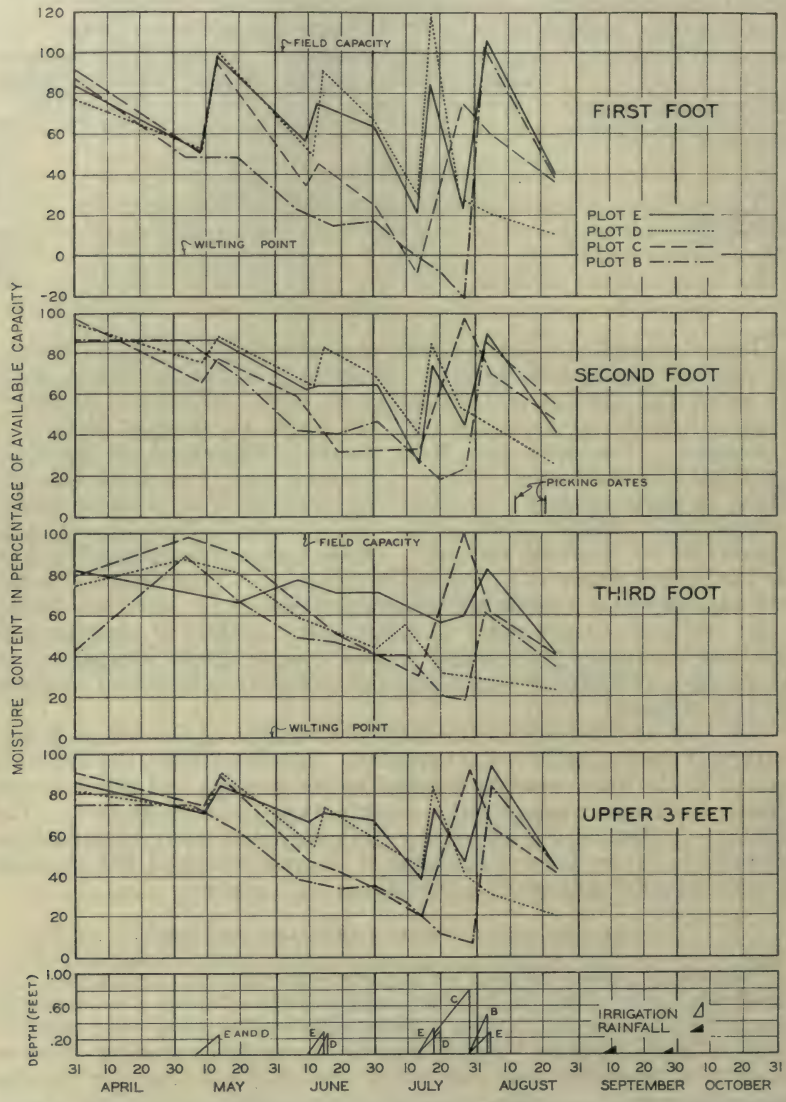

FIGURE 2.—Moisture content, expressed as a percentage of the available capacity, of each of the upper 3 feet and the average thereof, also rainfall and irrigation water applied, for the plots in the Fitch orchard in 1930. The heights of the triangles represent the depths of water applied by either irrigation or rainfall, and the bases show the periods of application.

this resulted in an even lower rate of water penetration. In later irrigation, very small streams were turned into each furrow, with the result that a longer time was required for the streams to reach the lower ends of the furrows, but in spite of that fact, it took less time to make application of a given depth of water by this method.

The extremely low degree of perviousness of this soil is illustrated by the fact that, after it became wet, a stream of 3 gallons per minute sufficed to keep a trickle for the full length of each one of the furrows in a plot containing about one third of an acre. This represents a rate of percolation of less than one half inch in 24 hours. It is probable that a large part of this amount was taken up by evaporation into the atmosphere. No attempt was made to correct the quantities of water applied in irrigation for the loss by direct evaporation.

Soil-moisture samples taken 2 to 5 days after each irrigation showed that in most cases the water applied had penetrated to the third and fourth feet. However, a number of instances when the moisture content of the fourth foot, and a few cases when that of the third foot, did not show any increase 2 to 5 days after irrigation were noted, whereas samples taken several days later did show an increase. Such results indicate that several days were required for the water to penetrate into the deeper subsoil.

FITCH ORCHARD, 1930

The moisture content of the soil in each of the upper 3 feet in each plot in the Fitch orchard during the season of 1930 and the average of the 3 are shown in figure 2. In this figure and in figures 4 to 8 inclusive, moisture content is shown as percentage of the available capacity of the soil mass. Rainfall and irrigation water applied also are shown. The heights of the rainfall triangles indicate the total depth of rain falling during each storm period that furnished more than one half inch of rain. For irrigations the height of each triangle likewise represents the depth of water applied during that irrigation. In both cases the bases of the triangles represent the periods during which the water was applied. The dates on which the fruit was picked also are shown.

Perhaps the most striking feature shown in figure 2 is the much more rapid loss of moisture, after irrigations, in the upper foot than in the second foot, and in the second than in the third foot. While it is very probable that this difference is due in part to loss of moisture from the first foot, both upward by evaporation and downward into the lower strata, it is not likely that such losses occur to an appreciable extent after the moisture content of the upper foot has fallen materially below the field capacity. The more rapid rate of moisture loss from the first foot as compared with the rates of loss from greater depths appears to continue when the moisture content in the upper foot is approaching the permanent wilting percentage, long after an irrigation.

The differences in rates of decrease of moisture at different depths appear to result mainly from differences in root concentration. Aldrich, Work, and Lewis [10] have shown that in soil 4 to 6 feet deep about 35 percent of the roots in the top 4 feet were in the upper foot, about 25 percent in the second foot, and about 20 percent in the third foot. The loss of moisture was much less in the deeper subsoil than from the upper soil and root concentration was very low. Since most of the feeding roots seem to be in the upper 3 feet, the moisture content of only this part of the soil mass is shown on the charts and considered in correlating soil moisture with the response of the trees.

[10] Aldrich, W. W., Work, R. A., and Lewis, M. R. See footnote 8.

Examination of the curves for plots B and C in figure 2 shows that the moisture content of the first foot fell below the permanent wilting percentage about July 10. In plot C this condition could have continued for only 4 or 5 days as this plot was irrigated beginning July 14. In plot B irrigation did not start until July 28 and the soil moisture in the first foot was below the permanent wilting percentage for about 2 weeks. The slope of a line representing the moisture content shows the rate at which the soil was losing water at any time, the steeper the slope the greater being the rate of loss. These curves do not indicate any slowing up in the loss of water from the first foot of soil when the moisture content approaches, and even when it falls below the permanent wilting percentage. In only a few cases has this continued rapid rate of loss been noted in these investigations.

The more usual condition found in these studies is brought out by the fact that in every case the curves of figure 2 show that before the soil moisture in the second and third feet and the average for the upper 3 feet dropped to 10 percent of the available capacity the rate of loss of moisture decreased. In most instances the break in the curves occurs at 20 or 30 percent of the available capacity. The significance of this break in the rate of withdrawal of water by the trees is that it helps to explain some of the effects of moisture content on the rate of growth of the fruit.

Table 3 shows the yield of fruit of each of the commercial sizes from each plot in the Fitch orchard in 1930.

TABLE 3.—*Yield of each size of pears from each plot in the Fitch orchard, 1930*

Commercial size (number of pears per standard box)	Yield from plot—							
	E		D		B		C	
	First picking	Second picking	First picking	Second picking	First picking	Second picking	First picking	Second picking
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
228	23	233	23	212	111	244	78	145
210	65	229	45	213	102	192	117	173
195	119	311	85	276	125	266	172	222
180–165	241	397	158	235	116	244	225	283
150	101	221	45	84	36	101	68	128
135	57	66	30	17	18	15	38	33
120	8	23	7	6	3	4	5	12
Total, each picking	614	1,480	393	1,043	511	1,066	703,	996
Total for each plot	2,094		1,436		1,577		1,699	
Total, 180's or larger	1,114		582		537		792	
Percentage 180's or larger	53.2		40.5		34.1		46.7	

The important feature of these data is the very much larger yield of pears of size 180 or larger from plot E, the most heavily irrigated plot. Bartlett pears of these sizes (180 and larger) are desirable for two reasons. (1) The size of the individual pears is a major factor in the yield in that a given number of pears of size 150 will fill 30 percent more boxes than will the same number of size 195. (2) The medium sizes (135 to 165, inclusive) are usually in greater demand on the markets and therefore bring better prices.

During the 1932 season, detailed studies were made of the effect of variations in soil moisture on the rate of growth of pear fruits in

the Fitch and Klamath orchards and also in the Medford Experiment Station orchard. These investigations are reported in greater detail elsewhere (*1*). [11] The results for 1932 show that as the season progressed the fruit grew more rapidly, with the most rapid growth occurring during the latter part of July for the Bartletts and during August for the Anjous. The Bartletts appeared to slow up slightly just before harvest.

Comparison of the rate of growth with the average moisture content for the upper 3 feet of soil showed that as the moisture content dropped the rate of growth also dropped. This is well shown by the two curves of figure 3 which indicate the rate of growth of fruit on plots E and B of the Klamath orchard in 1932. Reference to figure 8 will show that the soil moisture in plot B was not much below that in plot E before the middle of June, but that from then until July 23 plot B was much the drier of the two. During this period the rate of growth of the fruit on plot B was much slower than on plot E. Between July 23 and 25 plot B was irrigated and for about a week thereafter had as

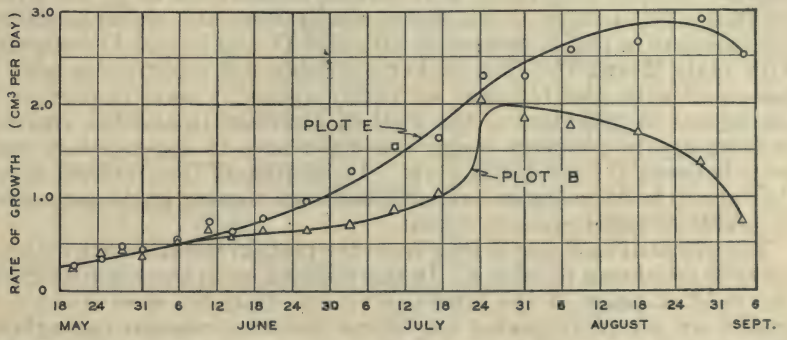

FIGURE 3.—Rate of growth of pears on plots E and B in the Klamath orchard in 1932, measured in cubic centimeters.

much moisture as did plot E. As a result the rate of growth on plot B was twice as great on July 25 as on July 18 and was nearly as rapid as it was on plot E. For the remainder of the season both moisture content and rate of growth fell off rapidly.

The data shown in figure 3 are somewhat typical of the results obtained on all three orchards. Since the rate of growth of pears is low in midseason as compared with late season, even when there is ample moisture in the soil, the effect of soil moisture on growth in the latter part of the season is relatively more important than it is in midseason.

The total yield in 1930 (table 3) was largest on plot E, the plot having the highest average moisture content during the season. There was very little difference in the yields of the other plots. One heavy irrigation was applied to plot C which seemed effective in increasing the size of fruit, hence plot C ranked second in the production of size 180 and larger.

At the time the plots in this orchard were selected it was thought that the size of the trees in the four plots was nearly the same. However, the fact that the yield of pears from plot D was smaller than the

[11] LEWIS, M. R., WORK, R. A., and ALDRICH, W. W. THE INFLUENCE OF DIFFERENT QUANTITIES OF MOISTURE IN A HEAVY SOIL ON THE RATE OF GROWTH OF PEARS. Unpublished report.

yield from any of the other plots, while the moisture content was intermediate between that of plot E on the one side and plot B on the other, led to a search for an explanation. An estimate of the top volume of the record trees in these plots was made by photographing each tree from two points so chosen that the lines of sight from the camera to the tree made angles of 90° at the tree. All photographs were made at the same distance from the trees. The total volumes of the tops of the five record trees in each plot as estimated from these photographs were as follows: Plot E, 1,904 cubic feet; plot D, 1,744 cubic feet; plot B, 1,983 cubic feet; and plot C, 1,848 cubic feet. Thus plot D had the smallest volume of top and this may explain the relatively low yield from this plot.

KLAMATH ORCHARD, 1930

Figure 4 shows the moisture data for the Klamath orchard plots during 1930. Here again the loss of moisture was most rapid in the upper foot of soil, with a progressive decrease in the rate at greater depths, but the differences were not so pronounced as in the Fitch orchard. The curves of this figure clearly show the higher available soil moisture in plot E compared with plot D, and in plot D compared with plots B and C. The higher available soil moisture in plot B compared with plot C is not so readily apparent upon inspection of the figure. Application of the method described in another article [12] is necessary to properly weigh the differences in soil-moisture contents between the two latter plots. Application of that method shows that plot B had the higher available moisture content at the time most favorable to rapid growth of fruit.

The yields of each size of fruit from the plots in the Klamath orchard for 1930 are shown in table 4. In this orchard, as in the Fitch orchard, the yield of pears of the larger and more desirable sizes was much greater on the plots having the higher moisture content throughout the season.

In this case the total yield from the plots is also clearly related to the soil-moisture content during the growing season. The marked effect of a low-moisture content during mid or late season is shown by comparison of the yield and size of the fruit from these plots with the associated soil-moisture content.

The total yield of plot E was about 300 pounds greater, and the yield of pears of size 165 and larger was about 350 pounds greater than that of plot D. This seems clearly related to the fact that in plot D the moisture content, as shown on figure 4, was lower than in plot E from about the middle of August until picking time. Plot B had about the same moisture content as plot D in the late summer, but was much drier during most of July, and the total yield of plot B was much smaller then, and the yield of the more desirable sizes was only half as great as the corresponding yields of plot D. Plot C was the driest of all the plots after about July 25, but had more moisture than plot B during most of July. The total yield on plot C was somewhat larger than that on plot B, but much smaller than on plots E or D. The higher moisture content of the soil of plot B as compared with that of plot C after July 25 may have been responsible for the slightly larger yield of medium-size fruit on the former plot.

[12] See footnote 1.

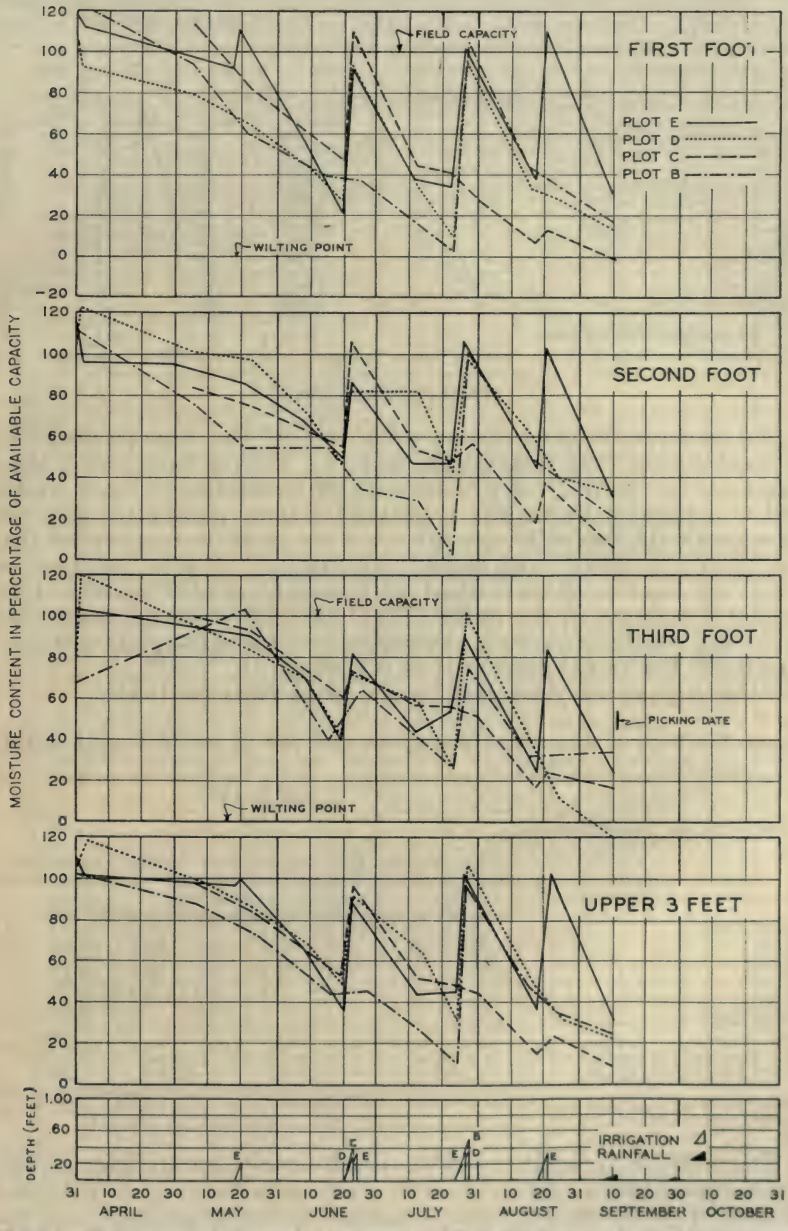

FIGURE 4.—Moisture content, expressed as a percentage of the available capacity, of each of the upper 3 feet and the average thereof, also rainfall and irrigation water applied, for the plots in the Klamath orchard in 1930. The heights of the triangles represent the depths of water applied by either irrigation or rainfall, and the bases show the period of application.

TABLE 4.—*Yield of each size of pears from each plot in the Klamath orchard, 1930*

Commercial size (number of pears per standard box)	Yield from plot—			
	E	D	B	C
	Pounds	*Pounds*	*Pounds*	*Pounds*
195 and smaller	186	239	391	560
180	75	87	79	109
165	226	231	194	204
150	164	177	109	103
135	496	423	191	148
120	229	146	48	38
110	161	104	20	10
100	158	65	8	6
90 and larger	80	15	0	0
Total	1,775	1,487	1,040	1,178
Total 165's and larger	1,514	1,161	570	509
Percentage of 165's and larger	85.3	78.1	54.8	43.2

FITCH ORCHARD, 1931

The moisture content of the soil of each of the plots in the Fitch orchard during 1931 is shown in figure 5. During that season there was a serious shortage of irrigation water in the Rogue River Valley and no irrigation water was available for these plots after June 25. As a result the moisture content in all the plots decreased after that date until the winter rains came. By August 5 all plots had reached about the same moisture content, with an average of 20 percent of the available capacity in the upper 3 feet. With low rainfall during the preceding winter and spring, the moisture in all of the plots was comparatively low in the early part of the season.

Table 5 gives the yield data for the Fitch plots for 1931.

TABLE 5.—*Yield of each size of pears from each plot in the Fitch orchard, 1931*

Commercial size (number of pears per standard box)	Yield from plot—							
	E		D		B		C	
	First picking	Second picking	First picking	Second picking	First picking	Second picking	First picking	Second picking
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
195 and smaller	10.9	4.5	21.4	15.8	21.8	24.3	38.9	29.4
180	24.9	24.8	35.4	46.3	30.5	125.6	58.0	146.7
165	240.5	111.6	187.2	91.8	248.9	310.8	199.5	176.1
150	118.7	12.4	77.8	11.9	75.3	69.7	71.8	79.3
135	170.1	2.0	58.3	6.0	58.8	13.4	100.2	12.9
120	250.4	23.9	71.7	23.4	39.9	4.5	49.8	17.9
110 and larger	71.8	1.5	7.9	.0	1.5	.0	5.4	.0
Total for each picking	887.3	180.7	459.7	195.2	476.7	548.3	523.6	462.3
Total for both pickings	1,068.0		654.9		1,025.0		985.9	
Total 165's and larger	1,003.0		536.0		822.8		712.9	
Percentage of 165's and larger	94.0		82.0		80.0		72.3	

The total yield of all the plots was much smaller in 1931 than in 1930, but the pears were larger. The fruit of all the plots was heavily thinned in an effort to secure large sizes in spite of the water shortage that was anticipated at the beginning of the season. As in 1930, the total yield and more especially the proportion of pears of the larger sizes was greatest on plot E, which had the highest soil-moisture content throughout the season. The yield from plot D was the lowest. As previously pointed out, this was probably due in part to the smaller size of the

trees in this plot. It is known that the moisture content of the soil of this plot was low during the preceding fall, winter, and spring, and this condition may have been partially responsible for the poor yield.

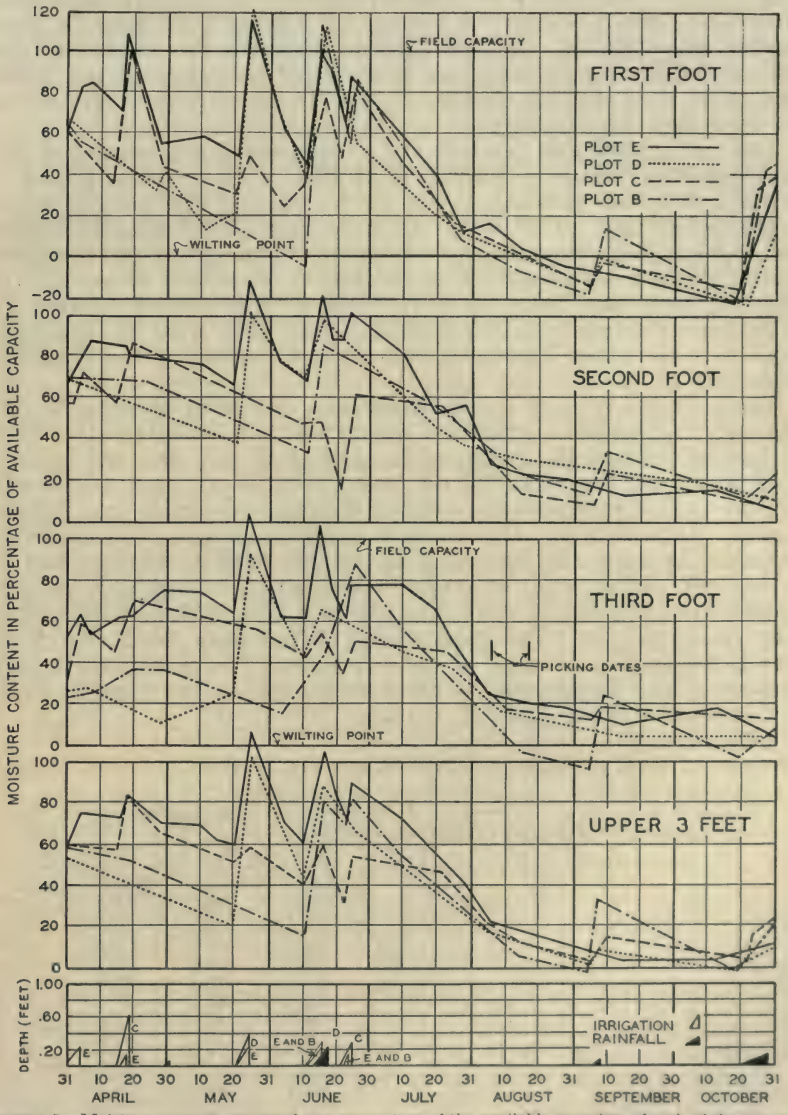

FIGURE 5.—Moisture content, expressed as a percentage of the available capacity, of each of the upper 3 feet and the average thereof, also rainfall and irrigation water applied, for the plots in the Fitch orchard in 1931. The heights of the triangles represent the depths of water applied by either irrigation or rainfall, and the bases show the period of application.

Almost one-third of the pears on plot E were 120's or larger, too large to bring the best price. It seems probable that somewhat less thinning in that plot would have resulted in a greater yield of the more desirable sizes.

KLAMATH ORCHARD, 1931

Figure 6 shows the soil moisture in the Klamath orchard during the 1931 season. At this orchard no irrigation water was available after July 15, and as a result the moisture content of all plots decreased after that date, reaching the permanent wilting percentage in September and October. As was the case with the Fitch orchard, the low rainfall during the winter of 1930–31 did not bring the soil moisture up to field capacity and all plots were comparatively dry up to the time they were irrigated.

The soil moisture in plots E and D was above 50 percent of the available water capacity during all of July, while on plots C and B it was below that amount during the last half of the month except in the second foot. Plot B was irrigated only once during the season and had less than 60 percent of the available capacity of soil moisture throughout the season except for the period from June 20 to July 13. The curves of this figure show very clearly the marked slowing up of the rate of moisture withdrawal from these plots when the moisture content in the upper 3 feet was from 20 to 40 percent of the available capacity.

The yields of fruit of the different sizes are shown in table 6. In spite of the fact that irrigation water was not available after July 15 and as a result the moisture content of all the plots fell rapidly after that date, the yield of fruit from the different plots was closely related to the soil-moisture content during the earlier part of the season. In plots E and D two-thirds of the pears were 165's or larger, while on the other two plots only about one-sixth of the fruit was of those sizes. This result appears to be due to the large difference in moisture content during the latter part of July and the smaller difference during August. The greater yield of fruit from plot E than from plot D was in part because of the larger fruit [13] in plot E and in part because of the larger number of pears per tree. The trees in these plots were not thinned during the year.

TABLE 6.—*Yield of each size of pears from each plot in the Klamath orchard, 1931*

Commercial size (number of pears per standard box)	Yield from plot—			
	E	D	B	C
	Pounds	*Pounds*	*Pounds*	*Pounds*
228	35.6	34.6	126.4	188.6
210	55.2	31.6	74.2	110.8
195	83.2	69.2	89.2	116.4
180	216.6	195.6	90.3	183.6
165	123.4	106.8	38.0	54.6
150	181.8	167.3	15.0	54.6
135	207.6	178.6	10.0	21.6
120	107.8	83.8	1.0	5.0
110	95.8	40.6	.0	.0
100	54.2	10.0	.0	.0
90 and larger	35.6	6.0	.0	.0
Total	1,196.8	924.1	444.1	735.2
Total 165's and larger	806.2	593.1	64.0	135.8
Percentage of 165's and larger	67.3	64.2	14.4	18.5

FITCH ORCHARD, 1932

The soil-moisture conditions in the Fitch orchard during the 1932 season are shown in figure 7. The quantity of soil moisture in the different plots during the season did not vary as much as was planned, nor as it did in other years. The most marked difference was in

[13] See footnote 11.

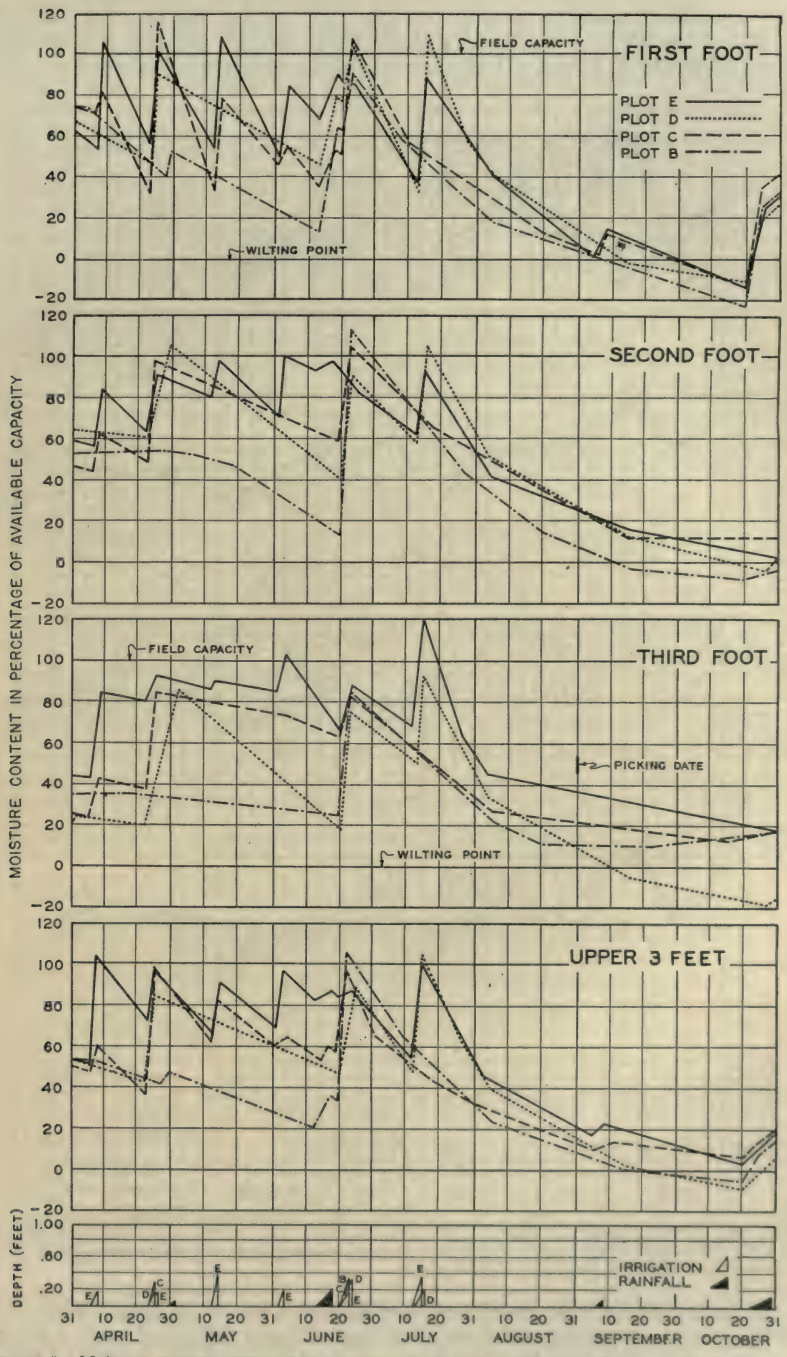

FIGURE 6.—Moisture content, expressed as a percentage of the available capacity, of each of the upper 3 feet and the average thereof, also rainfall and irrigation water applied, for the plots in the Klamath orchard in 1931. The heights of the triangles represent the depths of water applied by either irrigation or rainfall, and the bases show the periods of application.

the low soil moisture content of plot B during the period July 5 to 23. Plot D was materially drier than plot E during the period June 20 to July 5 and a little drier during the period July 5 to 25.

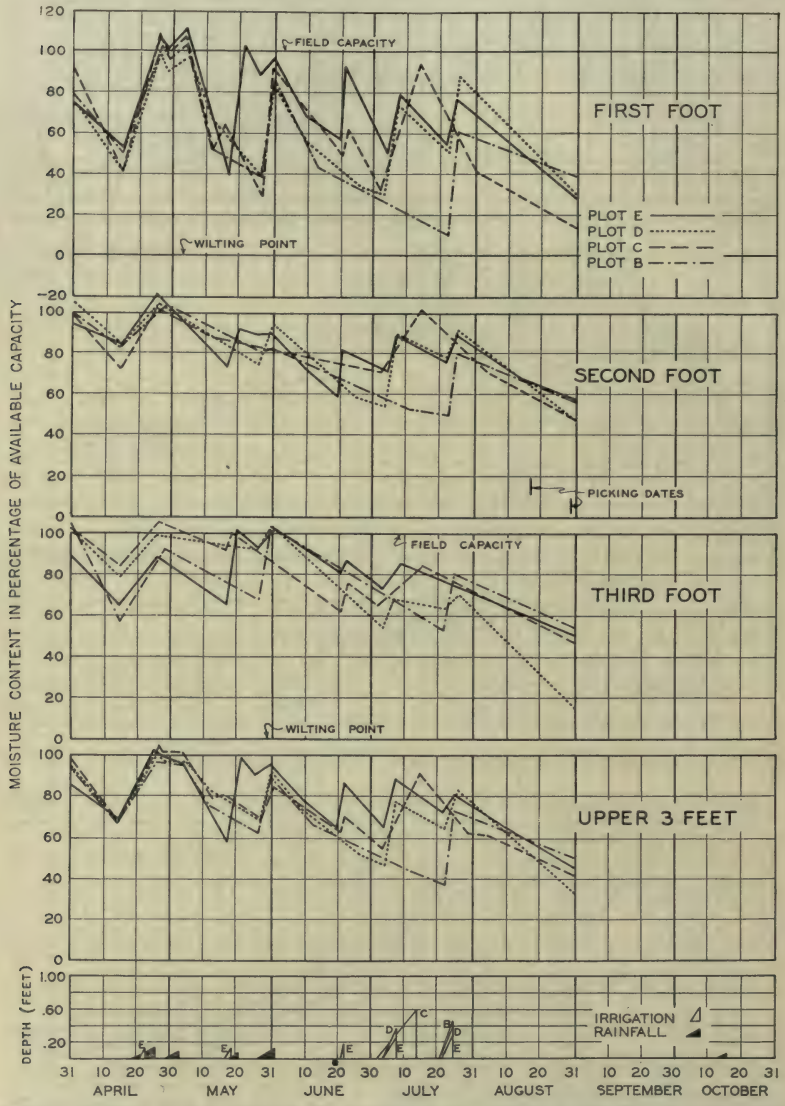

FIGURE 7.—Moisture content, expressed as a percentage of the available capacity, of each of the upper 3 feet and the average thereof, also rainfall and irrigation water applied, for the plots in the Fitch orchard in 1932. The heights of the triangles represent the depths of water applied by either irrigation or rainfall, and the bases show the periods of application.

Comparison of the moisture content of plot B during 1930 and 1931 with that during 1932 typifies the marked effect of both winter and summer rains on the moisture content of the soil in these plots. In mid-April 1930 the moisture content of the upper 3 feet in this

plot was 75 percent, and at the same date in 1932, 65 percent, yet in 1930, with no rainfall,the moisture content had dropped to 9 percent by July 23, while in 1932, with rain in late April and May, the content was still up to 38 percent at the corresponding date. During the winter of 1930–31 the highest moisture content reached by this plot was 72 percent of the available water capacity, while in the spring of 1932 the soil moisture was up to its field capacity. There was very little rain in the spring and early summer of 1931 and as a result the moisture content of this plot dropped to 16 percent on June 11 when the first irrigation commenced. . For plot C the high moisture content in the spring of 1932 and the rains during April, May, and June made it possible to keep the moisture content above 55 percent of the available capacity in the upper 3 feet throughout the growing season with one heavy irrigation applied in mid-July.

The yields and sizes of fruit from the different plots of the Fitch orchard in 1932 are shown in table 7. The comparatively small differences in the soil-moisture conditions and the relatively high moisture content in these plots during the 1932 season are reflected in the relatively uniform total yield of the plots and the uniformly high percentage of fruit of the larger sizes. As in the two earlier years, plot E had the highest yield as well as the highest moisture content. By computation from the data in table 7 it is found that the number of pears harvested from plot D was larger than the number harvested from any other plot. This fact, taken in connection with the smaller size of the trees on plot D, probably accounts for the smaller size of the fruit from plot D than from plot B in spite of the lower soil moisture in the latter plot during the greater part of July. Periodic measurement of the fruit on these plots showed that until August 11 (about 1 week before the first picking) the fruit on plot C was larger than that on either plot B or plot D. This is in accord with the higher soil-moisture content in plot C up to that time. After August 11 the fruit on plot B seemed to have grown faster, with the result that the yield and fruit size for plot B was greater than for plots C or D. This may be attributed, at least in part, to the higher moisture content in plot B during the last half of August.

TABLE 7.—*Yield of each size of pears from each plot in the Fitch orchard, 1932*

Commercial size (number of pears per standard box)	Yield from plot—							
	E		D		B		C	
	First picking	Second picking	First picking	Second picking	First picking	Second picking	First picking	Second picking
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
195 and smaller	15	32	21	245	6	106	1	191
180	103	17	78	105	47	85	37	82
165	229	64	167	246	183	147	130	215
150	414	93	178	228	249	245	192	258
135	133	223	69	138	105	216	81	200
120	234	57	49	30	102	59	65	53
110 and larger	18	66	1	19	1	29	1	21
Total each picking	1,146	552	563	1,011	693	887	507	1,020
Total for each plot	1,698		1,574		1,580		1,527	
Total 165's and larger	1,531		1,125		1,336		1,216	
Percentage of 165's and larger	90.2		71.5		84.6		79.6	

KLAMATH ORCHARD, 1932

Figure 8 shows the soil-moisture conditions which obtained in the plots of the Klamath orchard during the 1932 season. Moisture conditions in these plots during this season followed quite closely the prearranged plan.

Table 8 shows the yield of the different sizes of fruit from the Klamath plots in 1932. Perhaps the most striking feature in this tabulation is the close similarity of the percentages of fruit of the larger sizes in plots E, D, and C. While the percentages of 165's and larger in plots E and D are the same, there were more of the very large sizes in plot E and therefore the average size for the plot was larger.

The yields from plots E, D, and B appear to be very closely correlated with the moisture conditions in the plots. The fact that plot C matured only two-thirds as many pears as each of the other plots accounts for the larger size of the fruits on that plot as compared with what might have been expected from the moisture conditions in the different plots.

TABLE 8.—*Yield of each size of pear from each plot in the Klamath orchard, 1932*

Commercial size (number of pears per standard box)	Yield from plot—			
	E	D	B	C
	Pounds	*Pounds*	*Pounds*	*Pounds*
210	14.5	15.0	129.5	13.0
195	16.5	11.0	110.0	13.0
180	35.0	34.0	106.6	24.0
165	136.5	201.5	355.5	106.0
150	122.5	166.0	140.0	84.0
135	205.5	265.5	105.0	161.0
120	275.0	282.0	54.0	119.5
110	219.0	181.0	18.5	235.5
100	328.0	200.5	18.0	187.5
90	150.0	75.0	4.5	88.0
80 and larger	151.5	50.0	0.0	39.5
Total	1,654.0	1,481.5	1,041.6	1,071.0
Total 165's and larger	1,588.0	1,421.5	695.5	1,021.0
Percentage of 165's and larger	96.0	95.9	66.8	95.4

FRUIT GROWTH AND CROP YIELD

The results of the 3 years' experiments on the two orchards are consistent in showing that a high soil-moisture content throughout the season, more particularly during July and August, results in relatively rapid growth of the fruit. As a result the proportion of fruit of the larger sizes was uniformly higher on the more heavily irrigated plots. In the Klamath orchard, where the fruit was not thinned, the total yield of fruit also was greatest on the plots having the highest soil-moisture content. On the Fitch plots the thinning of the fruit, the smaller trees in plot D, and the variability of the yield of the different trees in each plot served to obscure the effect of soil moisture on total yield. Under the conditions that prevailed in connection with the Fitch-orchard experiments there seems to be sufficient reason for the belief that on heavily irrigated plots lighter thinning than that actually done would result in larger yields of Bartlett pears of the more desirable sizes, all other things being equal.

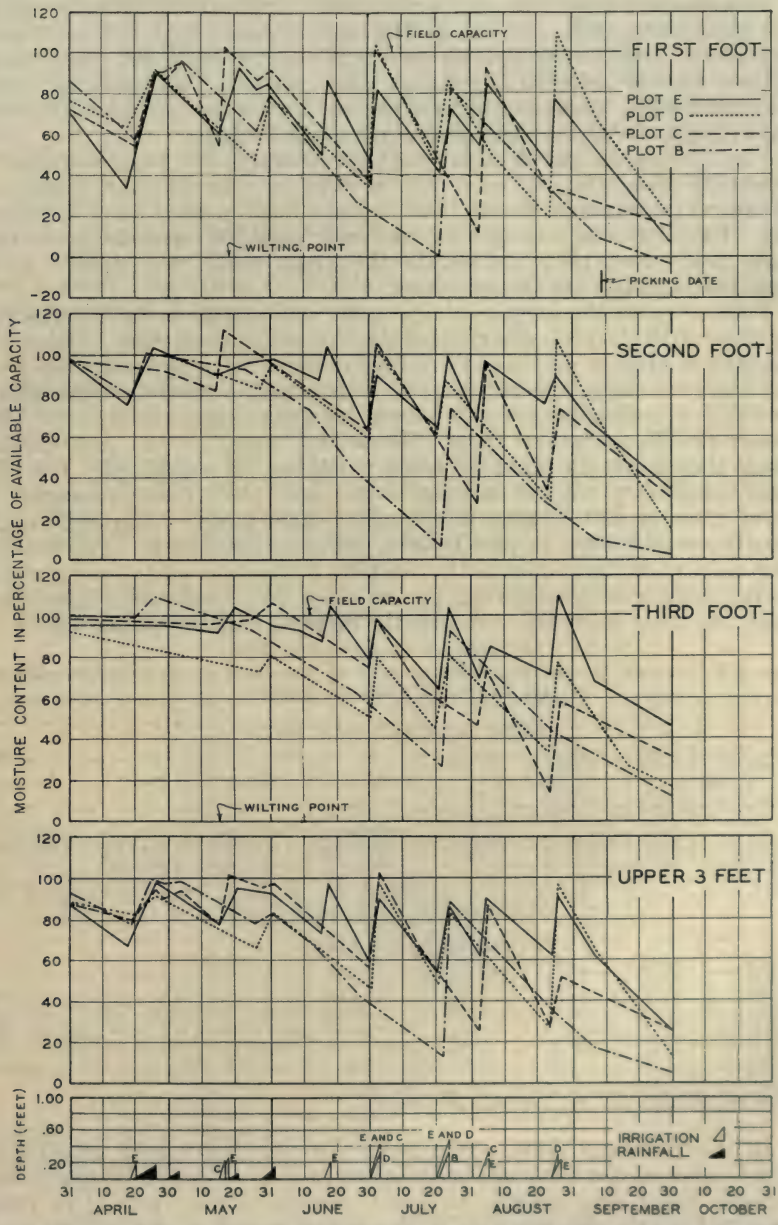

FIGURE 8.—Moisture content, expressed as a percentage of the available capacity, of each of the upper 3 feet and the average thereof, also rainfall and irrigation water applied, for the plots in the Klamath orchard in 1932. The heights of the triangles represent the depths of water applied by either irrigation or rainfall, and the bases show the periods of application.

SPUR AND SHOOT GROWTH

The average length of spur growth was determined by measuring 120 blossoming spurs on each of five trees in each plot. On the Bartletts in the Fitch orchard, both the spurs that set fruit and those that did not were included in arriving at the averages. For 1931 and 1932 only spurs that blossomed but did not set fruit were used in obtaining the averages for the Anjous in the Klamath orchard.

The average length of shoots in both orchards for 1931 was determined by measuring on each of five trees in each plot the length of 50 lateral or terminal shoots that had not been headed back in pruning. For 1932 the average was derived from 100 measurements for each tree. For 1931, terminals that had made no growth were included in obtaining the averages.

Table 9 gives the lengths of the spurs and shoots in both orchards together with the probable error of the average in each case. Although the length of spur and shoot growths reflects the vegetative vigor of the trees in these experiments, it is impossible to determine what periods of soil-moisture differences between plots resulted in the observed differences in vigor. Therefore, some of the plot differences shown by the data in table 9 cannot be explained. On the Fitch plots, top-volume measurements and yield records suggest a lower vigor in plot D than in the other three plots. Spur and shoot growth, usually least in plot D, also indicates low vigor. The important feature of these data is that in plot E the spur and shoot growth during 1932 was greater than in the other plots indicating increased vigor resulting from the consistently higher available soil moisture.

TABLE 9.—*Length of spur and shoot growths of pear trees in the different plots in the Fitch and Klamath orchards*

FITCH ORCHARD (BARTLETT)

Year	Growth	Plot E	Plot D	Plot B	Plot C
		Centimeters	*Centimeters*	*Centimeters*	*Centimeters*
1931 [1]	Spurs	1.10±0.024	0.67±0.019	1.00±0.059	1.08±0.028
1932 [1]	do	1.54± .017	1.34± .014	1.38± .015	1.45± .015
1931	Shoots	14.0 ± .55	8.4 ± .36	7.1 ± .34	11.8 ± .57
1932	do	36.9 ± .65	27.6 ± .51	29.9 ± .57	32.2 ± .56

KLAMATH ORCHARD (ANJOU)

1931 [2]	Spurs	1.58±0.015	1.59±0.015	1.36±0.012	1.62±0.013
1932 [2]	do	1.98± .009	1.92± .010	1.62± .012	1.94± .011
1931	Shoots	33.2 ± .63	22.0 ± .59	15.4 ± .47	11.2 ± .54
1932	do	32.3 ± .46	26.5 ± .34	20.9 ± .28	31.6 ± .42

[1] All blossoming spurs, regardless of type, used in average.
[2] Only blossoming, nonsetting spurs used in average.

In the Klamath plots, explanation for the larger spur growth in plot C than in the other plots during 1931 is not readily found. The slightly larger spur growth of plot E compared with plot C in 1932 may be the cumulative effect of the consistently higher available soil moisture in the former plot during three seasons. The shorter spur growth in plot B than in the other plots in 1931 and 1932 indicates the lower vigor resulting from less available soil moisture. The greater shoot growth in plots E and D than in plots B and C during

1931 indicates greater vegetative vigor resulting from higher available soil moisture during 1930 and 1931. In 1932 plots E and D again showed greater shoot length than plot B. The greater relative amount of shoot growth in plot C as compared with the other plots in 1932 than in 1931 can probably be attributed both to larger amounts of soil moisture during June 1932 and to the lighter crop on plot C in 1932. In general, these data indicate larger spur and shoot growth in plots with more available soil moisture.

Figure 9 shows typical trees in plots E and B in the Klamath orchard at the end of the third (1932) season of these experiments. The larger number of long shoots on the tree in plot E than on the tree in plot B indicates the greater vegetative vigor resulting from the greater quantities of available soil moisture during the three seasons in plot E than in plot B.

BLOSSOM AND SET OF FRUIT

In March 1933 data on the amount of bloom and the set of fruit on the various plots for the previous years were obtained. For this purpose 120 spurs were selected at random from each of the record trees in each plot. The portions of each spur produced in each of the 3 years 1929, 1930, and 1931, were classified as either nonblossoming, blossoming but not setting fruit, or blossoming and holding fruit. The data given in table 10 are derived from this classification.

TABLE 10.—*Blossom and set of fruit on the different plots of the Fitch and Klamath orchards, 1929–32*

FITCH ORCHARD (BARTLETT)

Year	Growth	Plot E	Plot D	Plot B	Plot C
1929	Blossom [1]	82±2.1	81±1.6	88±1.9	87± 1.9
	Set [2]	44±1.5	41±1.7	63±1.6	59± 2.5
1930	Blossom [1]	81±2.5	72±2.0	85±0.8	78± 1.2
	Set [2]	70±2.4	69±2.1	80±2.3	69± 3.4
1931	Blossom [1]	28±3.3	25±2.2	48±2.8	53± 4.0
	Set [2]	66±2.9	75±3.0	90±1.8	87± 1.8
1932	Blossom [3]	53±4.4	54±1.8	56±3.5	44± 2.3
	Set [4]	92±5.9	87±7.0	76±7.5	97±10.1

KLAMATH ORCHARD (ANJOU)

1929	Blossom [1]	79±4	79±1	83±1	87±6
	Set [2]	59±8	48±6	34±3	49±3
1930	Blossom [1]	82±1	83±1	86±1	88±1
	Set [2]	64±4	45±5	38±2	48±4
1931	Blossom [1]	76±1	76±2	84±2	92±1
	Set [2]	30±1	11±2	8±2	16±2
1932	Blossom [3]	25±2	26±2	45±4	33±1
	Set [4] May 17	76±5.4	82±7.1	41±2.6	56±3.5
	Set [4] Aug. 15	30±4.2	32±2.2	14±1.6	15±1.7

[1] Blossom expressed as percentage of spurs blossoming.
[2] Set expressed as percentage of blossoming spurs carrying fruit.
[3] Blossom expressed as percentage of growing points blossoming.
[4] Set expressed as number of fruits carried per 100 blossoming points.

The blossom records for 1932 were determined by counting all growing points and all blossoming points on three small limbs on each record tree in each plot. The set records were subsequently obtained by counting all the fruits on each of those limbs. These data, which give "percent of growing points blossoming" and "fruits per 100 blossoming points", also are shown in table 10.

Some of these data seem inconsistent. More detailed information must be secured as to the time and causes of fruit-bud differentiation

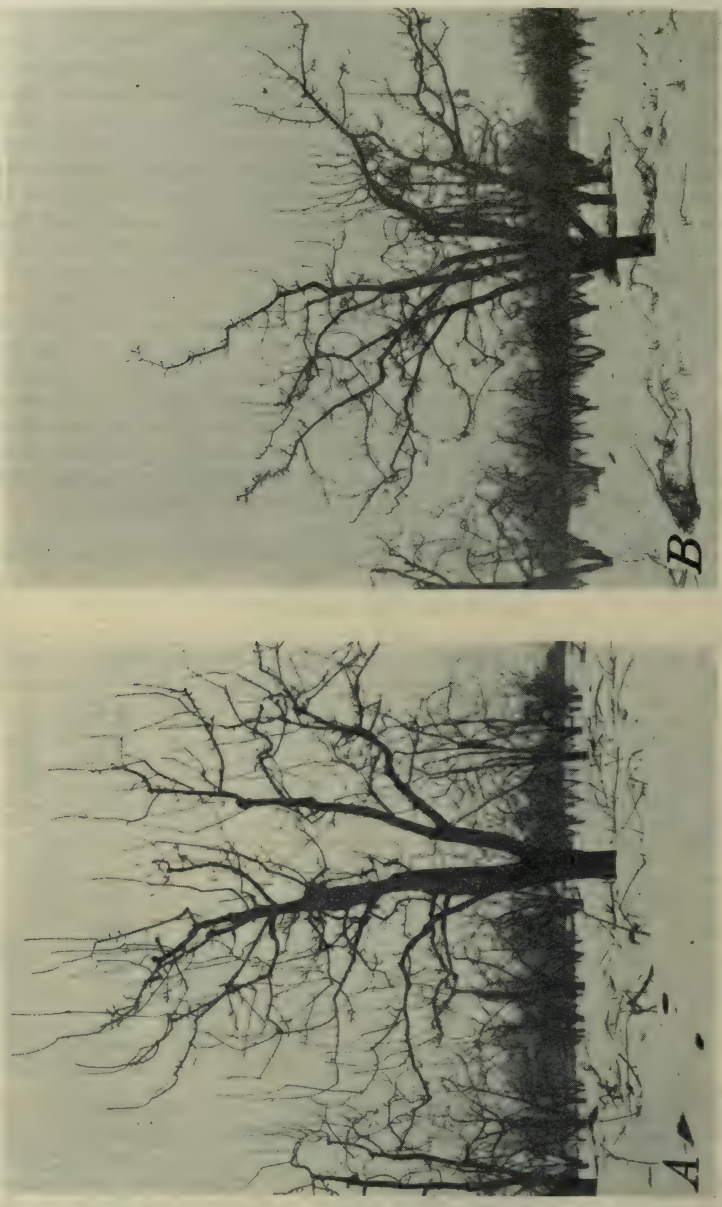

FIGURE 9.—Typical trees in plots E and B of the Klamath orchard in February 1933, showing the longer and more abundant shoot growth on plot E: *A*, Tree in plot E; *B*, tree in plot B.

and of the set and drop of fruit before definite conclusions can be drawn as to the effect of soil moisture on these tree responses.

QUALITY OF FRUIT

During each of the 3 years fruit from both orchards was saved from each plot and carefully examined for its dessert and keeping qualities. This study was made by F. C. Reimer, superintendent of the Southern Oregon Branch Experiment Station. Also additional observations on the quality of the Anjou pears from the Klamath orchard in 1932 were made by C. L. Powell, formerly junior physiologist, Bureau of Plant Industry, United States Department of Agriculture.

Slight differences in the fruit from the different plots were noted, but they were of little if any commercial importance. From these studies it seems safe to conclude that the different irrigation treatments carried on in these studies and the different soil-moisture conditions observed have not caused any differences of commercial importance in the quality of the fruit.

EFFECT ON VIGOR OF THE TREES

The data regarding the spur and shoot growth on the trees in the different plots show that the trees on the more heavily irrigated plots made the best growth. A similar result is shown in table 11, which gives the average increase in the circumference of the trunks of the record trees in each plot in both orchards.

TABLE 11.—*Average circumference of trunks of record trees in each plot in August 1930 and in March 1933 and the average increase between those dates in the Fitch and Klamath orchards.*

Orchard	Plot E			Plot D			Plot B			Plot C		
	1930	1933	Increase	1930	1933	Increase	1930	1933	Increase	1930	1933	Increase
	Centimeters	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*
Fitch	53.0	55.6	2.6	51.4	52.9	1.5	53.7	56.1	2.4	53.8	55.8	2.0
Klamath	70.0	75.6	5.6	69.6	74.1	4.5	70.6	74.1	3.5	69.1	73.8	4.7

Observation of the trees in the different plots discloses no evidence of injury of any kind on account of the very frequent irrigation of some of the plots. No detailed records have been kept of the incidence of blight or of winter injury, but there seems to have been no difference between the various plots. It should be kept in mind that both of these orchards are well drained and that while the more heavily irrigated plots have been irrigated very frequently each application has been small and there has been no water-logging of the land. It should also be remembered that the experiment has continued for only 3 years and it is impossible to tell what may be the effect of the different irrigation treatments if carried on for many years.

ECONOMIC ASPECTS OF THE RESULTS

These studies, together with those on the Medford Experiment Station reported in more detail elsewhere (*5*), have shown that whenever the soil moisture in the upper 3-foot average fell much below 70 percent of the available capacity the rate of growth of fruit was reduced.

It necessarily follows that with initially the same amount of crop the plots having the higher moisture content produced the larger average size of fruits and greater tonnage. Other factors, however, such as the difficulty of carrying on the spray program, the cost of irrigation, and the possible bad effect of keeping the soil continuously wet must be considered.

These experiments were not designed to show the effect of thinning in connection with irrigation and the data do not show the relation between the two practices. However, there seems to be no reason to question that the proportion of excessively large Bartlett pears on the most heavily irrigated plots in the Fitch orchard could have been reduced or eliminated by less severe thinning, with a resultant increase in the total yield.

By means of a tabulation of typical sales of Bartlett and Anjou pears from Medford on the New York auction during 1930, 1931, and 1932, the average prices at which pears of four different-size groups sold have been estimated. The data are shown in table 12.

TABLE 12.—*Estimated average price per pound* [1] *paid for Bartlett and Anjou pears from Medford on the New York auction, 1930–32*

BARTLETT

Year	Price per pound for pears of indicated size			
	180's and smaller	165–150	135–120	120's and larger
	Cents	*Cents*	*Cents*	*Cents*
1930	3.7	4.5	4.8	4.8
1931	6.1	6.6	6.2	5.9
1932	3.5	3.7	3.8	3.5
Average	4.4	4.9	4.9	4.7

ANJOU

1930	5.0	5.6	5.9	5.7
1931	7.1	8.2	8.0	7.1
1932	3.5	4.3	3.9	3.8
Average	5.2	6.0	5.9	5.5

[1] These prices are based on an estimated net weight of 46 pounds per packed box for the Bartlett and 45 pounds for the Anjou pears.

From these data it is evident that the sizes of fruit that obtain the highest prices vary from year to year but that both very small and very large fruit are nearly always discounted.

Table 13 shows the effect of the different soil-moisture conditions in the various plots on the returns to the grower. This effect would be harder to see and understand if the prices used in the tabulation varied from year to year. For this reason the average values of the various sizes of fruit for the 3-year period shown in table 12 have been used in all 3 years in table 13. In preparing table 13 the value of the actual yield of fruit of each group of sizes for each plot shown in tables 3 to 8, inclusive, was determined. A uniform cost of harvesting and marketing the fruit has been assumed at 4 cents per pound or $1.84 per box.

TABLE 13.—*Estimated returns to grower from pears of different sizes from each plot on the Fitch and Klamath orchards, based on the average New York auction price from 1930 to 1932, inclusive, and on an assumed harvesting and marketing cost of 4 cents per pound or $1.84 per box*

FITCH ORCHARD (BARTLETT)

Year and plot	180 and less	165 and 150	135 and 120	120 and larger	Total	Estimated yield per acre	
						Boxes	
1930							
E	$5.19	$5.77	$1.39		$12.35	637	$172.90
D	4.20	2.92	.54		7.66	437	107.24
B	4.88	2.85	.36		8.09	480	113.26
C	4.63	4.06	.79		9.48	516	132.72
1931							
E	.26	4.35	4.01	$0.51	9.13	325	127.82
D	.48	3.32	1.43	.06	5.29	200	74.06
B	.81	6.35	.97	.01	8.14	310	113.96
C	1.09	4.74	1.63	.04	7.50	300	105.14
1932							
E	.67	7.20	5.82	.59	14.28	518	199.92
D	1.80	7.37	2.57	.14	11.88	480	166.32
B	.98	7.42	4.34	.21	12.95	481	181.30
C	1.24	7.16	3.59	.15	12.14	452	169.96

KLAMATH ORCHARD (ANJOU)

1930							
E	$3.13	$17.72	$10.41	$1.20	$32.46	425	$354.86
D	3.91	16.62	5.98	.22	26.73	355	294.03
B	5.64	9.88	1.44		16.96	249	186.56
C	8.03	9.10	.81		17.94	282	197.34
1931							
E	4.69	10.26	4.90	.52	20.37	286	224.07
D	3.97	9.06	2.55	.09	15.67	221	172.37
B	4.56	1.26	.02		5.84	106	64.24
C	7.19	2.62	.08		9.89	176	108.79
1932							
E	.79	9.30	15.62	4.53	30.24	395	332.64
D	.72	12.66	12.60	1.88	27.86	354	306.46
B	5.23	12.00	1.73	.06	19.02	270	209.22
C	.60	7.02	10.30	1.92	19.84	256	218.24

On the basis of market value, the difference between 4.4 and 4.9 cents per pound for Bartletts and between 5.2 and 6 cents per pound for Anjous does not appear highly important but when the cost of harvesting and marketing the fruit—which is practically the same per pound or per box regardless of size—is substracted from the market value the importance of securing fruit of proper size is evident. The difference in the return to the grower would have been that between 0.4 and 0.9 cent per pound for Bartletts and between 1.2 and 2 cents per pound for Anjous. In other words, on the basis of the average value for the 3-year period, Bartletts of sizes 120 to 165, inclusive, would have returned to the grower more than twice as much as those of sizes 180 and smaller, and similarly Anjous of the more desirable sizes would have returned almost twice as much.

As uniform prices were used in making up table 13, the effect of size on growers' returns can be illustrated by comparing the returns per acre of Fitch plot C in 1930 with those of Fitch plot E in 1932. The total yields of these two plots were almost identical, yet, on account of the more desirable sizes of the fruit on the more frequently irrigated plot E, the return was 50 percent greater on that plot. In the Klamath orchard practically the same total yield from plot E in 1931 returned almost 15 percent more than that from plot C in 1930.

The effect of these soil-moisture conditions on the return to the grower is due partly to the effect on size, as discussed above, and partly to the effect of total yield. An inspection of that part of

table 13 reporting results from the Fitch orchard shows that in each year the return from plot E has been greatest and that from plot D smallest. The bearing of the smaller size and apparently poorer vigor of the trees in plot D on the yield of that plot has been explained. The returns from plots B and C have been almost the same over the 3 years. On the whole, soil-moisture conditions in the latter two plots have not been very different. The return to the grower emphasizes that (1) a high moisture content will produce larger fruit than a low moisture content, (2) too small a set of fruit or too heavy thinning in connection with a high moisture content will result in fruit of too large size, and (3) a profitable use of frequent irrigation requires that the number of fruits on the trees be great enough to produce a large yield of desirable sizes of pears.

In the Klamath orchard the table shows that in each year the return was best from the plot having the highest moisture content and decreased in the other plots in the same order as the moisture content. These data show very clearly the higher return which may be secured by maintaining a high moisture content in this heavy soil.

The average cost of irrigation on horse and tractor farms as determined by Besse, Brown, and Wilcox (*2*) is $3.34 per acre for each application. It is often considered necessary to cultivate after each irrigation and, although the authors do not believe this to be true, the cost of such cultivation, found in the same study by Besse, Brown, and Wilcox to be $1.35 per acre [14] for each cultivation, may be added to that of applying water. When this is done it is possible to estimate the additional cost per acre of maintaining a high moisture content throughout the season.

Table 14 shows the number of applications of irrigation water and the total depth applied to each plot on the 2 orchards during the 3 seasons.

TABLE 14.—*Irrigations and total depth of water applied on each plot on the Fitch and Klamath orchards, 1930–32*

FITCH ORCHARD

Plot	1930		1931		1932	
	Irrigations	Depth	Irrigations	Depth	Irrigations	Depth
	Number	*Feet*	*Number*	*Feet*	*Number*	*Feet*
E	4	1.12	5	1.00	5	0.95
D	3	.92	2	.63	2	.79
B	1	.51	2	.48	1	.45
C	1	.79	2	.89	1	.60

KLAMATH ORCHARD

E	4	1.18	6	1.61	7	2.02
D	2	.64	3	.82	3	1.09
B	1	.48	1	.35	1	.32
C	1	.39	2	.57	3	.90

Table 15 is designed to show the increased return to the grower by reason of more frequent irrigation. It shows the increases or decreases in dollars per acre in the return to the grower on plots E, D, and C, as compared with plot B, on each orchard, the increased

[14] Unpublished data.

costs of irrigation of plots E, D, and C as compared with those of plot B, and the net gains or losses.

As has been stated before, the trees of plot D in the Fitch orchard were smaller and apparently less vigorous than those on the other plots in that orchard. It is believed that this accounts for the lower returns from that plot.

It should be remembered that the Bartlett pears on the plots in the Fitch orchard were thinned in an attempt to secure comparable leaf-fruit ratios each year. However, in 1930 plot E was not thinned a second time as were the other plots. The result was that in 1930 plot E produced the largest yield of fruit of desirable sizes and made the greatest return to the grower after subtracting the cost of the extra irrigations applied to this plot. In the two later years, while plot E produced the largest yields, many of the pears were too large to bring the highest price with the result that the larger return from this plot as compared with that from plot B was just great enough to take care of the cost of the extra irrigations. It is believed that if this plot had not been so heavily thinned it would have shown a profit by reason of the extra irrigation. Plot C received the same number of irrigations as plot B during each of the 3 years, and the return to the grower over the 3 years was practically the same from each of the two plots.

TABLE 15.—*Increases or decreases per acre between estimated return, cost of irrigation, and net gain or loss to the grower from plots E, D, and C as compared to estimated returns from plot B in the Fitch and Klamath orchards, 1930–32*

Year and plot	Fitch orchard (Bartlett)			Klamath orchard (Anjou)		
	Return	Cost of irrigation	Gain (+) or (−) loss	Return	Cost of irrigation	Gain (+) or (−) loss
1930						
E	+$59.64	+$14.07	+$45.57	+$168.30	+$14.07	+$154.23
D	−6.02	+9.38	−15.40	+107.47	+4.69	+102.78
C	+19.46	[1].00	+19.46	+10.78	[1].00	+10.78
1931						
E	+13.86	+14.07	−.21	+159.83	+23.45	+136.38
D	−39.90	[1].00	−39.90	+108.13	+9.38	+98.75
C	−8.82	[1].00	−8.82	+44.55	+4.69	+39.86
1932						
E	+18.62	+18.76	−.14	+123.42	+28.14	+95.28
D	−14.98	+4.67	−19.65	+97.24	+9.38	+87.86
C	−11.34	[1].00	−11.34	+9.02	+9.38	−.36

[1] The same number of applications were made on these plots as on plot B.

The results for the Klamath orchard are much more consistent and, it is believed, give a much more accurate picture of the results that can be expected from irrigation on these heavy soils. In each year both plot E and plot D showed a very substantial increase in the per acre return to the grower after subtracting the cost of more frequent irrigation. In 1931 two irrigations on plot C returned an increase over one irrigation on plot B. On the other hand three irrigations on plot C in 1932 did not increase the return over that from plot B enough to make up for the extra cost of irrigation.

The comparison between results obtained on plots D and C in 1932 in the Klamath orchard shows the relatively greater importance of a high soil moisture in the latter part of the season. Both plots received three irrigations and nearly the same total depth of water. However,

plot D was irrigated late in August, whereas plot C received its last irrigation early in August. Therefore the moisture content in the soil of plot D was higher during the last month of the growing season. Plot D, with a much larger number of pears than plot C, produced almost as large fruit and a much heavier yield. Estimates of the average size of pears on these two plots from soil-moisture conditions indicate that if the trees had borne the same number of pears those on plot C would have been considerably smaller.

DUTY OF WATER

By reference to table 14 it will be noted that the maximum depth of irrigation water applied to a plot in the Fitch orchard was 1.12 feet in depth and in the Klamath orchard, 2.02 feet. By reference to table 15 it will be noted that the net return after subtracting the cost of extra irrigations from plot E in the Klamath orchard in 1932, which received the maximum quantity of 2.02 feet of water, was only about $7.50 more per acre than that from plot D which received only 1.09 feet in depth of water. It seems probable that a depth of 1.50 [15] feet will give practically maximum returns under the conditions of these experiments.

The normal duty of water delivered to the farm, in the Medford and Talent irrigation districts is about 1.5 acre-feet per acre; that is, a depth of 1.5 feet over the irrigated acreage. It thus seems evident that the requirement for irrigation water for the production of maximum yields of pears on heavy soils such as those in the Fitch and Klamath orchards is not greater than the normal supply in these districts. Other sections of the Rogue River Valley have more, rather than less water for irrigation.

SUMMARY AND CONCLUSIONS

The rate of growth of the fruit was found to be very closely related to the moisture content of the upper 3 feet of soil. Studies of the effect of soil moisture on the rate of fruit growth have shown that whenever the moisture content fell below 70 percent of the available capacity, the rate of growth of the fruit was reduced.

The rate of growth of the fruit was greatest during the latter part of the growing season and thus the effect on the size of fruit at harvest of a low moisture content late in the season was greater than the effect of equally low soil moisture earlier in the season.

A high soil-moisture content was conducive to long spur and shoot growth. There appeared to be no correlation between variations in the storage or dessert quality and differences in soil moisture.

High soil moisture was conducive to the production of fruit of the larger and more desirable sizes. When Bartlett pears were heavily thinned, the plots having high soil moisture produced pears that were too large to bring the highest prices.

The thinning practice in the orchard should be coordinated with the irrigation practice in order that pears of the most desirable sizes and heavy yields may be obtained.

The plots having the highest soil moisture produced the largest yields and the greatest return to the grower.

On the Klamath orchard, the cost of the extra irrigation required to maintain high soil moisture was not as great as the return from the

[15] This estimate makes no allowance for surface waste or other losses.

higher yields when the return was based on the average of the New York auction prices for Medford pears for the 3 years of the study.

On the Fitch orchard the results were confused by the small size of the trees in one plot and by the thinning practice but these results are not believed to contradict those found on the Klamath orchard.

The requirement for irrigation water to maintain a high soil-moisture content on the heavy soil of these orchards was no greater than the normal duty of water for which the Medford and Talent irrigation systems were designed.

In some years the water supply to the Medford and Talent Irrigation Districts has been insufficient to meet the requirements. At other times the available supply has been more than sufficient to provide a net duty of 1.5 acre-feet per acre. It would seem to be most profitable in the long run to conserve by storage all water not urgently needed in years of excessive supply, in order that it may be available later in a period of deficiency.

The data reported herein indicate clearly that number of irrigations, depth applied, or both combined are not always reliable indexes of soil-moisture conditions. The data show that it was always difficult, and often impossible, to obtain penetration of irrigation water to the entire root zone in amounts sufficient to raise the soil moisture to field capacity. If methods of securing more adequate penetration were known it is certain that as frequent irrigation as was necessary in the most frequently irrigated plots described herein would not be necessary. It is recommended that an available soil-moisture content of not less than 50 percent of capacity be maintained. The number of irrigations necessary to accomplish this will vary from season to season and from orchard to orchard.

The only known way to be sure that soil moisture is present in readily available form is by frequent examination of the subsoil by the use of a soil auger or similar tool.

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A REVISIONAL STUDY OF THE GENUS SCOLYTUS GEOFFROY (ECCOPTOGASTER HERBST) IN NORTH AMERICA[1]

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INTRODUCTION

For several years field workers of the Division of Forest Insects of the Bureau of Entomology have been hampered by the uncertainty that exists regarding the identity of several of Leconte's species of *Scolytus* and by the fact that a number of more or less common western species are without names. With the beginning of intensive field investigation of certain fir engraver beetles associated with the dying of fir trees, particularly in recreational areas in the Pacific Coast States, it became important that the identity of such associated species of *Scolytus* be definitely determined. It was especially desirable to establish the identity of *S. ventralis* Leconte, *S. subscaber* Leconte, *S. sulcatus* Leconte, and *S. californicus* Leconte.

[1] The writer wishes to express his gratitude to J. M. Miller, of this Bureau's Pacific coast laboratory (Berkeley, Calif.), for the adequate series of *Scolytus subscaber*. Through his active and critical interest it is now possible definitely to establish the identity of this species, which appears not to have been taken since the time of Leconte. Thanks are also due to J. C. Evenden and W. D. Bedard, of the Coeur d'Alene (Idaho) laboratory, and F. P. Keen, of the Portland (Oreg.) laboratory, for valuable material from their respective regions; to J. M. Swaine for the opportunity to study the types of his species of *S. tsugae* Swaine and *S. monticolae* Swaine; and to Nathan Banks for making the Leconte collection available for study.

Swaine, in his epochal Canadian Bark Beetles (*39, 40*),[2] established the identity of most of Leconte's species. His work indicated rather conclusively the identity of *S. ventralis*, but unfortunately he was not able definitely to separate it from *subscaber*. In fact *subscaber* has often been confused with *ventralis*, perhaps partly because Leconte's type series contains but one specimen of *subscaber* and several specimens of *ventralis*, and especially because only the female of *subscaber* has been known. Recently, however, J. M. Miller, in charge of field work on forest insects in California, has sent in a number of specimens comprising both males and females, the females of which the writer finds to agree with Leconte's type of *S. subscaber*.

ECONOMIC IMPORTANCE OF THE GENUS

The genus *Scolytus* is not only of taxonomic interest as the chief North American representative of one of the main subdivisions of the bark beetles, but it also contains species that are of considerable economic importance as well.

One of the most destructive forest insects in the Eastern States is the hickory bark beetle (*S. quadrispinosus* Say), which under favorable climatic conditions kills large numbers of hickory trees of all species. Thousands of these trees in central New York were killed by this species during the years 1912 to 1923 (Blackman, *2, 4*). Similar outbreaks have occurred at various times elsewhere in the eastern half of the country, and it seems certain that the hickory bark beetle is the the most serious enemy of hickory trees in this region.

The fir bark beetle (*Scolytus ventralis*), while perhaps not quite so deadly as the hickory bark beetle, is of decided economic importance. For many years it has been observed that considerable numbers of fir trees, *Abies concolor* especially, have been dying each year in the Pacific Coast and Rocky Mountain States. The burrows of *S. ventralis* are nearly always found in such trees, and there is evidence that this beetle, by its attacks over a period of years, is an important factor in the death of the trees. The relationship between these bark beetles and certain other organisms, the combined activities of which kill the trees, is the subject of research by other members of the Division of Forest Insects. The destruction of white fir trees would not be of great importance if we considered only their timber value, but in recreational areas this tree is a valuable one and its destruction means not only an esthetic loss but a financial one as well.

Several other western species of bark beetles are apparently just as aggressive as *S. ventralis* but at present are not of economic importance because the trees they affect are not of great value. With the further development of recreational areas, home sites, and so forth, the insect enemies of many trees now considered of little value will assume a much greater economic importance.

In addition to the native species of *Scolytus*, two species have been accidentally introduced from Europe and have occasioned considerable anxiety in recent years. Other introductions, some of which may prove of greater importance, will be prevented only by continued vigilance. The two introduced species already established are the shot-hole borer, or fruit tree bark beetle, (*S. rugulosus* Ratz.) and the smaller elm bark beetle (*S. multistriatus* Marsh.).

[2] Italic numbers in parentheses refer to Literature Cited, p. 28.

The shot-hole borer has been known in this country since 1878, when it was reported from Elmira, N.Y., by Leconte (Hubbard and Schwarz, *21*). In a very few years it was known from Massachusetts, New York, New Jersey, Pennsylvania, Maryland, North Carolina, and Missouri. It soon became distributed throughout most of the States east of the Rocky Mountains and in southern Ontario, and it has more recently been reported in New Mexico, California, and Oregon. Damage by this species is usually confined to orchards where sanitation has been neglected and the vigor of the fruit trees has been allowed to deteriorate.

The smaller elm bark beetle was first reported in this country in 1910 from Cambridge, Mass., by Chapman (*9*). Here it was found breeding in the larger limbs and tops of elm trees weakened by the leopard moth (*Zeuzera pyrina* L.). It is not known to be responsible for independent injury, but it breeds in trees decadent from the attacks of other insects or from other causes. It has not spread so rapidly as the shot-hole borer, but the writer has seen specimens taken in Massachusetts, in Connecticut, on Long Island and elsewhere in New York, in Pennsylvania, and in New Jersey. At the present time (1934) it is abundant in the vicinity of Newark, N.J., and appears to be closely associated with the Dutch elm disease, a serious outbreak of which has recently been discovered there. The possible insect vectors of this disease are being investigated and the preliminary evidence seems to point unmistakably to the smaller elm bark beetle as an important agent in its transmission.

Another European form, *Scolytus scolytus* (Fab.), is not known to be established in this country. This species, known as the larger elm bark beetle, is an important vector of Dutch elm disease in Europe and is also important as an enemy of elm trees on its own account. Several recent shipments of logs from Europe to veneer factories in this country have been intercepted and found to contain living adults and brood of this bark beetle (as well as several other species of insects); so it would not be surprising to find that it has been established either at the ports of entry or in the vicinity of veneer factories.

NOMENCLATURE

The status of the names *Scolytus* Geoffroy (1762) (*14, v. 1, p. 310*) and *Eccoptogaster* Herbst (1793) (*15, p. 124*) has been the subject of considerable dispute during recent years, although prior to the beginning of the present century the former name was accepted as valid by all but a few workers on the group. This dispute was rendered acute in 1903 by the attack of Ganglbauer (*13*) and his supporters on the validity of Geoffroy's name, Weise (*43*) being the leader in the opposing views.

The ruling of the Fifth Zoological Congress in 1901 which established the present law of priority was intended to put an end for all time to the question of the validity of genera and species. However, it seems not to have had this effect, in the case of Geoffroy's names at least, owing to the difference of opinion as to the exact meaning of "binary nomenclature" and also as to what constitutes an adequate description or definition.

Thus, Hopkins (*18, 19*) and a few other workers on the bark beetles have held firmly to Geoffroy's name, while Reitter (*28, 29*) and

Spessivtseff (36) have wavered. Swaine (*37, 40*), following Ganglbauer (*13*), Trédl (*41*), and others, substituted the generic name *Eccoptogaster* Herbst for *Scolytus* Geoffroy and was followed in this by several others, including the present writer (Blackman, *1, 2*). In 1918 Swaine (*40*) gave as his reason for rejecting *Scolytus* Geoffroy his opinion that "Geoffroy's description seems entirely inadequate", his use of binary as opposed to binomial names, and his failure to designate a species.[3] Others have advanced similar reasons for rejecting *Scolytus* Geoffroy.

The rules distinctly state that binary names are acceptable. Geoffroy mentions only one "species", describes it, and illustrates it, and both description and illustration are at least as good as those of the majority of writers of his time whose species and genera have in most cases been accepted without question by later workers. Both Fabricius (*11, p. 59*) in 1775 and Linné (*24*) in 1788, as well as Müller (*26*) in 1764 and Schaeffer (*34*) in 1766, apparently proved the adequacy of the description by recognizing the species in question, although the first two of these assigned it to another genus (*Bostrichus*).

It would seem, then, that the rejection of Geoffroy's genus *Scolytus* has been contrary to the letter and spirit of the law of priority and has resulted in a grave injustice to one of the ablest entomologists of his time.

A peculiar aspect of the situation has more recently (1923) been brought to light by Sampson (*32*), who states:

> Dr. A. F. Fourcroy, in 1785, published a small book in Paris entitled "Entomologia Parisiensis", the preface of which states that the trivial [i.e., specific] names therein were added by Geoffroy himself to rectify the omissions in his original work, and on page 139 of the first volume the specific name of "*niger*" is added to *Scolytus*.

This would seem unquestionably to establish priority for *Scolytus* Geoffroy over *Eccoptogaster* Herbst, although in the present writer's opinion the original publication was sufficient. Of course this does not alter the status of the specific name (*scolytus*) proposed by Fabricius in 1775.

For other discussions of this controversy reference may be made to Hopkins (*19, pp. 219, 220*), Swaine (*40, pp. 50, 51*), and Von Butovitsch (*6, pp. 2–5*). The last-named especially discusses the question in considerable detail, particularly regarding the controversy between Ganglbauer, Weise, and others.

HISTORY OF THE SPECIES OCCURRING IN NORTH AMERICA

Say's description (*33, pp. 323–324*) of *Scolytus quadrispinosus*, which appeared in 1826, applies only to the male and allows it to be readily recognized. The female, however, as is often the case in this genus, is quite different in the structure of the abdomen and was described as a distinct species under the name *S. caryae* by Riley in 1867 (*30*). Riley's type series, now in the United States National Museum, contains many typical males of *quadrispinosus* Say as well as many of the females described as *caryae* Riley, and it would seem that the identity of *caryae* and *quadrispinosus* might well have been inferred by the presence of the two in the same host and habitat. Leconte in 1868 (*44*) recorded *quadrispinosus* Say and *caryae* Riley

[3] Swaine in personal letters now states that he is convinced of the validity of *Scolytus* Geoffroy.

as separate species, the latter based on "three specimens which show no sexual difference." However, in 1876 Leconte (*22*) placed *caryae* as a synonym of *quadrispinosus*, a disposition of the name which Riley (*31*) accepted in 1881.

Scolytus muticus Say (*33*) is described on the same page as the preceding species. The characters are so distinctive that it has been recognized by later workers almost without exception.

Eccoptogaster (=*Scolytus*) *rugulosus* Ratzeburg was described from Germany (*27*) in 1839, and was first noted in North America by Leconte (Hubbard and Schwarz, *21*) in 1878. The numerous references to it in American literature deal for the most part with the economic rather than the taxonomic aspects.

Scolytus fagi Walsh was described (*42*) in 1867. Only a few references to this nonabundant species are in the literature.

Scolytus californicus Leconte was described (*44*) in 1868 from a single specimen obtained from Andrew Murray and purporting to have come from California. No authentic specimens have been taken since, although Smith (*35*) reported it in 1886. It is apparently identical in all respects to *S. scolytus* (Fab.).

Scolytus sulcatus Leconte was described (*44*) in 1868 from a single specimen bearing a New York locality label. No other authentic specimen was collected until September 1933, but since then it has been taken on several occasions in connection with investigations on the Dutch elm disease and its insect vectors.

Scolytus ventralis Leconte was described (*44*) in 1868 from two specimens taken in Washington State. Other samples of this species were associated by Leconte with his types of *subscaber* and *ventralis*. It remained unrecognized until the publication of Swaine's key and brief description (*40*). Hopping (*20*) lists as hosts *Pseudotsuga taxifolia*, *Abies concolor*, *A. grandis*, and *A. magnifica*.

Scolytus unispinosus Leconte was described (*22*) in 1876 from two male specimens taken in Oregon. In 1878 Leconte (Hubbard and Schwarz, *21*) recorded a specimen taken in Michigan, but in 1879 Leconte (*23*) pointed out the differences between this specimen and *unispinosus*. The specimen in question is almost certainly *S. piceae* Swaine, described many years later. In 1879 Leconte (*23*) also recorded *unispinosus* from Colorado. Smith (*35*) in 1886 gave a brief account of its biology. Swaine (*40*) and Hopping (*20*) reported this species as common on Douglas fir in western Canada. Hopkins (*16*, *17*) and Currie (*10*) in 1905 recorded it from red fir and western larch in the Pacific coast, Cascade, and Rocky Mountain regions. Chamberlin (*7*) in 1917 added *Picea engelmannii* as a host.

Scolytus praeceps Leconte was described (*22*) in 1876 from specimens taken in California, both sexes being represented. Later references by Hopkins (*16*, *17*) and Currie (*10*) give the hosts as white fir and grand fir and the distribution as California and Idaho. Fall and Cockerell (*12*) in 1907 reported it from New Mexico.

Scolytus subscaber Leconte was described (*22*) from a composite series, the type specimen being from Vancouver Island. Leconte's type series includes also other specimens from Oregon and California, but these are really *S. ventralis*. Later references to it by Hopkins (*17*), Currie (*10*), Fall and Cockerell (*12*), Burke (*5*), and Chamberlin (*8*) appear to have been based on erroneous determinations and should apply to *S. ventralis*.

Eccoptogaster (=*Scolytus*) *piceae* Swaine was described (*38*) in 1910 from specimens taken in Quebec, Canada, from *Picea canadensis*. It was later (1918) found breeding in eastern larch in New York by Blackman and Stage (*3*), and Swaine (*40*) in the same year reported it as occurring throughout Canada as far west as Alberta.

Eccoptogaster (=*Scolytus*) *tsugae* Swaine was described (*39*) in 1917 from British Columbia and Alberta, the hosts being mountain hemlock and Douglas fir.

Eccoptogaster (=*Scolytus*) *monticolae* Swaine was described (*39*) in 1917 from specimens taken from white pine and Douglas fir in British Columbia.

Scolytus multistriatus was described by Marsham (*25*) in 1802. It is a European form first seen in this country at Cambridge, Mass., and reported by Chapman (*9*) in 1910.

DESCRIPTION OF THE GENUS

The body form is cylindrical, stout, usually but little more than twice as long as wide; the color, brown to black, usually shining; the sculpture, weak to moderate, with the pubescence on the upper surface usually sparse.

The head has the front usually flattened and more hairy in the male, and convex in the female. The eye is elongate, wider above, with the inner line broadly and shallowly emarginate. The antenna has the scape short, the funicle seven-jointed and shorter than the club, which is flattened, irregularly ovate, with three sutures, the first distinct and sclerotic, the others indistinct.

The anterior legs have the tibiae stout, the edges nearly parallel and devoid of teeth, produced into a prominent curved process at the outer distal angle, the inner angle acute but not produced beyond the tarsal insertion; the tarsi are slender, often nearly as long as the tibiae, the third joint more or less strongly bilobed.

The pronotum is large, more or less strongly constricted near the anterior margin, the disk usually finely punctured, with an elevated margin at the sides and behind.

The scutellum is large, triangular, more or less deeply depressed between the elytra.

The elytra are shining, the bases without an elevated margin, often scabrous in the females, not declivitous but usually slightly depressed at the apex.

The venter of the abdomen is either concave or ascending abruptly behind, often with the second, third, and fourth sternites ornamented with carinae, tubercules, spines, or elevated margins, especially in the males; the fifth sternite is often shorter in the males.

KEY TO THE NORTH AMERICAN SPECIES

A. Abdominal sternites unarmed in both sexes, the second not concave; elytra with their bases not strongly scabrous in either sex.

B. Elytra clothed with hairs over entire surface, striae and interspaces about equally impressed; epistomal process reduced or lacking.

C. Smaller, less than 2.5 mm long; elytra with short hairs over entire surface; frons feebly convex, aciculate to margin, with epistomal process reduced; venter of abdomen gradually ascending, suture between first and second sternites not elevated to form a marginal line, fifth sternite not sulcate in either sex ..... *rugulosus* Ratz. (p. 10).

CC. Larger, usually about 4.00 mm long; elytra with long hairs over entire surface; frons very broadly flattened in both sexes, feebly concave in male, epistomal process lacking, margin smooth; fifth sternite of male with median sulcus.
muticus Say (p. 11).

BB. Elytra with disk glabrous, striae more deeply impressed than interspaces; epistomal process variable.

C. Fifth sternite lacking an elevated posterior margin in one sex; elytra with humeri less prominent.

D. Elytra with striae distinctly impressed, punctures markedly coarser than on interspaces; frons densely granulate-punctate, epistomal process obsolete; fifth sternite of male without an elevated posterior margin, that of female with distinct margin, closely punctured.
fagi Walsh (p. 11).

DD. Elytra with striae weakly impressed, punctures but little coarser than on the interspaces; frons finely aciculate-punctate, epistomal process reduced; fifth sternite without an elevated posterior margin in the unique type, moderately punctured ..... *sulcatus* Lec. (p. 12).

CC. Fifth sternite with an elevated posterior margin in both sexes; elytra with humeri more prominent.

D. Fifth sternite short in both sexes, in male scarcely longer than fourth sternite, posterior margin subangulately rounded, very strongly elevated especially in male; third and fourth sternites with longer hairs at sides; elytra with striae weakly to moderately impressed, apex usually notched opposite third interspace; epistomal process more narrowly and deeply emarginate.

E. Fifth sternite in male with posterior margin strongly extended in median line and recurved, subrostriform; second sternite less strongly margined in front; elytra more strongly notched at apex.
reflexus, n. sp. (p. 13).

EE. Fifth sternite in male with posterior margin strongly elevated but not subrostriform in median line; second sternite more strongly margined in front; elytra less strongly notched at apex.
wickhami, n. sp. (p. 13).

DD. Fifth sternite longer in both sexes, in male nearly as long as third and fourth combined; third and fourth sternites with hairs at sides not notably longer; elytra with apex usually not notched; epistomal process more broadly and shallowly emarginate.

E. Elytral striae usually feebly impressed, punctures small, interspaces not at all or feebly impressed; second sternite shining, punctures fine but deep; usually smaller ..... *monticolae* Swaine (p. 15).

EE. Elytral striae usually rather strongly impressed, punctures coarser, interspaces usually distinctly impressed; second sternite opaque or subopaque, finely but not so deeply punctured; usually larger ..... *tsugae* Swaine (p. 15).

AA. One or more of abdominal sternites carinate, tuberculate, or armed with one or several teeth or spines in male at least (sometimes reduced or even lacking in *subscaber* Lec., *praeceps* Lec., *oregoni*, n. sp., and *robustus*, n. sp.); second sternite either concave or convex; base of elytra usually scabrous in female.

B. Second sternite, in male at least, deeply concave, with anterior margin strongly extended, and typically carinate in median line; female with second sternite either similar or convex with a more weakly elevated anterior margin and carina reduced or lacking.

C. Frons of male very broadly, feebly concave, fringed with long incurved hairs, in female feebly convex and hairs sparser; antennal club very broad, 1.2 times as

long as wide; second sternite with a median carina in male, third and fourth with spines, fifth very short; in female, venter of abdomen opaque, unarmed, fifth sternite as long as third and fourth together; elytra with striae coarsely punctured, strongly impressed, base not scabrous in either sex ..... *quadrispinosus* Say (p. 16).

CC. Frons of male not so broadly flattened, with hairs usually sparse and more evenly distributed, that of female convex; antennal club usually more than 1.5 times as long as wide; second sternite armed in male at least, others unarmed; fifth sternite concave in both sexes, usually at least nearly as long as third and fourth together; elytra with striae not strongly impressed, base scabrous or subscabrous in the females.

D. Second sternite in male concave and carinate, carina sometimes reduced or even obsolete; convex in female, carina absent.

E. Venter of abdomen subopaque in both sexes; second sternite in male very finely, sparsely, obsoletely punctured, in female convex and moderately punctured; elytra of female scabrous at base, subscabrous to about middle; usually larger ..... *subscaber* Lec. (p. 17).

EE. Venter of abdomen shining; second sternite with carina absent in female and greatly reduced or even obsolete in male,[4] punctures numerous in both sexes; elytra scabrous only at the base in female; usually smaller.

F. Second sternite broadly rounded in front, very coarsely punctured, anterior margin sharply elevated in female, strongly extended in male; fifth sternite longer than third and fourth together in both sexes; southern Rocky Mountains ..... *robustus*, n. sp. (p. 19).

FF. Second sternite more narrowly rounded in front, less coarsely punctured, anterior margin thick, distinctly elevated in both sexes, but not so strongly extended in male as in foregoing species; fifth sternite in male shorter than third and fourth together; Northwestern States ..... *oregoni*, n. sp. (p. 18).

DD. Second sternite concave in both sexes, anterior margin strongly extended, opaque or shining, carina usually well developed in males at least.

E. Second sternite opaque, finely and more closely punctured, the carina usually well developed in male, usually absent in female. *praeceps* Lec. (p. 20).

EE. Second sternite subopaque or moderately shining, not closely punctured, carina well developed in both sexes, strongly elevated anteriorly in male to form a spinelike process.

F. Larger, more than 2.7 mm long; second sternite subopaque, punctures very fine and sparse, nearly obsolete ..... *opacus*, n. sp. (p. 20).

FF. Smaller, less than 2.4 mm long; second sternite feebly or moderately shining, punctures moderately fine and sparse. *abietis*, n. sp. (p. 21).

BB. Second sternite in both sexes vertical or oblique, not concave, usually convex, armed with a tubercle, spine, or median carina, anterior margin moderate or weak, more extended; other sternites unarmed, except in *multistriatus* and *scolytus*.

[4] When the carina is absent, members of this subgroup may be recognized by the shining venter and the strongly elevated or extended anterior margin of the second sternite.

C. Second sternite with carina or base of tubercle or spine reaching posterior margin.

D. Larger, usually more than 3.6 mm long; second sternite with carina or tubercle on posterior margin in both sexes, often obsolescent in female.

E. Elytral striae distinctly impressed, punctures on interspaces 2 and 3 confused, finer than on striae; venter of abdomen shining, segment 2 with a faint median carina often ending in a small tooth at posterior margin, segments 3 and 4 each with a small rather sharp median tooth on posterior margin, segment 5 impressed in median line and posteriorly, with a strong posterior margin (*californicus* Lec.) *scolytus* (Fab.) (p. 22).

EE. Elytral striae scarcely impressed; punctures of interspaces in rows and but little finer than those of striae; venter of abdomen subopaque, segment 2 with a small median tooth, often obsolescent in females, segments 3 and 4 unarmed, segment 5 concave with a strong posterior marginal ridge. *ventralis* Lec. (p. 22).

DD. Smaller, usually less than 2.7 mm long; second sternite with a spine in the male, a tubercle in the female; striae more strongly, but variably, impressed, interstrial punctures considerably finer and sparser.

E. Frons of male more vertical, weakly convex, flattened on an area extending only slightly behind the eyes; pronotum more finely and sparsely punctured; elytral striae more strongly impressed; second sternite opaque, very finely and sparsely punctured, base of spine extending to center of segment; fifth sternite nearly as long as third and fourth combined, its posterior outline arcuate. *sobrinus*, n. sp. (p. 23).

EE. Frons of male more sloping, flattened well behind eyes; pronotum less finely, more closely punctured; elytral striae more weakly impressed; second sternite shining or subopaque, punctures stronger; fifth sternite but little longer than fourth, posterior outline arcuate or subangulate.

F. Frons of the male feebly concave, more coarsely aciculate-punctate and with coarser hairs; elytral interspaces not impressed; second sternite shining, with a stout blunt spine, its base extending from posterior margin to well beyond center of segment; fifth sternite little longer than fourth, its posterior outline subangulate *laricis*, n. sp. (p. 24).

FF. Frons not concave in either sex, finely to moderately aciculate-punctate, with finer hairs; elytral interspaces feebly impressed; spine on second sternite more slender.

G. Frons in male moderately coarsely aciculate-punctate, slightly convex, the hairs fine and rather short; strial punctures moderate; second sternite shining, base of spine extending past middle of segment; fifth sternite scarcely longer than fourth, its posterior margin subangulately rounded. *fiskei*, n. sp. (p. 25).

GG. Frons of male finely aciculate-punctate, hairs fine and longer, strial punctures finer; second sternite subopaque, base of spine reaching center of segment; fifth sternite with its posterior margin nearly evenly arcuate.
unispinosus Lec. (p. 26).

CC. Second sternite with base of tubercle or spine not attaining the posterior margin.

D. Elytra subtruncate behind, striae strongly punctured, moderately but variably impressed, interspaces not impressed; pronotum distinctly wider than long, strongly constricted near anterior margin; venter of abdomen not closely punctured; second sternite with a spine or tubercle arising from center in both sexes; fifth sternite in male shorter than third and fourth combined.
piceae Swaine (p. 26).

DD. Elytra separately rounded behind, striae and interspaces nearly equally impressed; pronotum scarcely wider than long, moderately constricted near anterior margin; venter of abdomen finely and densely punctured, second sternite with a spine arising from anterior third in both sexes; fifth sternite in both sexes longer than third and fourth combined.....*multistriatus* Marsh. (p. 27).

DESCRIPTIONS OF NORTH AMERICAN SPECIES

SCOLYTUS RUGULOSUS Ratzeburg

Male.—Dark reddish brown to black, with margins reddish brown; 1.8 to 2.3 mm long exclusive of head, about 2.3 times as long as wide.

Front of head varying from slightly convex to flattened, occasionally feebly concave in median area; very finely convergently aciculate, with punctures very fine and inconspicuous, with sparse, fine, cinereous hairs of moderate length; epistomal process nearly obsolete. Eye elongate, scarcely wider above the broad, shallow emargination. Antenna yellowish, club 1.7 times as long as funicle, 1.6 times as long as wide, slightly wider distally.

Pronotum slightly wider than long, posterior outline nearly straight, rounded at posterior angles, sides convergently arcuate, feebly constricted near anterior margin, broadly rounded in front; surface shining, with coarse, rather close, elongate punctures, much denser on sides and in front; posterior and lateral margins strongly developed.

Elytra about equal in width to pronotum; humeri elevated and polished, sides convergently arcuate, separately rounded behind and rather strongly emarginate in sutural region; not dehiscent; margin finely and sharply serrate; surface subopaque, moderately strongly depressed about scutellum, which is wider than long; surface feebly shining, striae and interspaces subequally strongly impressed, and equally, moderately punctured, punctures larger toward base, those from interspaces bearing fine, short, erect hairs; posterior fifth sloping.

Venter of abdomen strongly, obliquely ascending, not excavated, first and second sternites fused, second sternite not margined anteriorly, punctures fine and close, pubescence cinereous, consisting of many short, fine, appressed hairs and a few longer, stouter ones; third and fourth sternites very short, each ornamented by a submarginal row of longer hairs; fifth sternite about twice as long as preceding two combined, not strongly margined behind.

Female.—Frons slightly convex, less flattened and less hairy than in male, but otherwise very similar to male.

This species, introduced from Europe, has become widely distributed in North America. The writer has studied specimens from Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, Maryland, the District of Columbia, Ohio, Indiana, Illinois, Michigan, Missouri, Kansas, Colorado, Texas, Louisiana, Mississippi, Georgia, North Carolina, Virginia, West Virginia, and Kentucky. The hosts given include apple, pear, peach, and both the wild and cultivated species of plum and cherry. It has also been reported from quince and nectarine.

SCOLYTUS MUTICUS Say

Male.—Shining black, but often with elytra dark reddish brown; 2.8 to 4.3 mm long exclusive of head, about twice as long as wide; with sparse long hairs over most of surface.

Front of head very broadly flattened, distinctly concave; epistomal margin broadly and strongly emarginate, epistomal process lacking; surface shining, very coarsely aciculate, with sparse, fine, obscure punctures and sparse, very fine, long hairs; finely, densely punctured at margin, with a dense fringe of coarser, longer, incurved, yellow hairs. Eye elongate, wider above, broadly emarginate, its shape usually modified at upper median angle by extreme flattening of head. Antenna yellowish brown, club 1.55 times as long as funicle, 1.55 times as long as wide, ovate, moderately wider distally, sutures angulate.

Pronotum wider than long, widest just behind middle; posterior outline distinctly bisinuate, sides arcuate, rather weakly constricted near anterior margin; surface shining, strongly, moderately closely punctured except in middle half of median line, which is feebly, broadly elevated and devoid, or nearly so, of punctures; punctures coarser at sides, and much denser in anterior constriction; posterior-lateral margin strongly developed; disk glabrous, but with long slender hairs at sides and shorter ones in front.

Elytra about equal to pronotum in width; humeri strongly elevated and polished, sides distinctly arcuate, slightly converging caudad, separately rounded behind, with sutural region broadly, shallowly emarginate; margin obsoletely serrate; surface shining, very strongly depressed in scutellar region, striae and interspaces equally, strongly, coarsely punctured and impressed, interstrial punctures bearing long, slender, yellow hairs; posterior seventh rather weakly depressed and confusedly punctured.

Venter of abdomen shining, strongly, rather closely punctured, with long, slender hairs; second sternite nearly vertical, convex, anterior margin thick, elevated; third and fourth sternites short; fifth sternite with ventral face short at each side, extended and longitudinally impressed in median region, finely, deeply punctured; posterior face concave at each side, very finely, closely punctured and ornamented with a dense tuft of long, dorsally recurved hairs at each side.

Female.—Frons not quite so broadly flattened, slightly less coarsely aciculate, with sparse punctures more conspicuous and fringe of hairs less strongly developed. Elytra distinctly serrate on posterior portion of sides. Fifth abdominal sternite much longer than preceding two combined, and moderately finely, deeply, and closely punctured.

The specimens studied by the writer are all from *Celtis* when the host is cited, and came from New Jersey, Pennsylvania, Maryland, the District of Columbia, West Virginia, Ohio, Kentucky, Kansas, Texas, Mississippi, and Florida.

SCOLYTUS FAGI Walsh

Male.—Dark reddish brown to black, 4.5 mm long exclusive of head, about 2.15 times as long as wide.

Front of head flattened, sometimes feebly concave; epistoma devoid of process, margin broadly emarginate; surface shining, rather densely granulate-punctate, punctures passing over into aciculae near epistoma, ornamented with numerous short, fine, erect, yellow hairs. Eye elongate, scarcely wider above, inner line very broadly and shallowly emarginate. Antenna yellowish brown, club 1.22 times as long as funicle, 1.7 times as long as wide, nearly regularly elliptical, sutures strongly angulate.

Pronotum slightly wider than long, widest just behind the middle, posterior outline nearly straight, sides convergently arcuate, scarcely constricted near anterior margin, very broadly rounded in front; surface shining; punctures on disk fine, moderately spaced, coarser and closer at sides and in the weak anterior constriction; marginal line distinct and elevated on sides and behind.

Elytra very slightly narrower than pronotum, about 1.3 times as long as wide, widest near base, with sides convergently arcuate, broadly rounded behind and slightly emarginate in sutural region; sides feebly serrate, apex entire except in emargination; surface brightly shining, strongly depressed near scutellum; striae strongly impressed (not so strongly as in *quadrispinosus*), punctures coarse, separated by less than their own width; interspaces with much finer, sparse

punctures, usually not impressed; posterior sixth moderately depressed, punctures close and confused, some of them bearing short setae.

Venter of abdomen somewhat concave, brightly shining, coarsely, densely punctured; second sternite oblique, separated from first by an elevated margin; third and fourth sternites short, the two together shorter than the fifth, which is convex, longitudinally impressed, and the ventral face not limited by a raised posterior margin, very densely punctured, posterior face finely and densely pubescent.

Female.—Front of head convex, finely and closely punctured, and ornamented with a few short, fine hairs. Elytra as in male. Venter of abdomen more coarsely punctured; second sternite shorter; fifth sternite much longer than third and fourth together and with a strongly elevated arcuate posterior margin.

This species has been reported from Illinois and Texas, the hosts being *Fagus* and *Celtis*. Several series from Texas have been studied by the writer.

SCOLYTUS SULCATUS Leconte

Type.—Reddish brown (probably immature), 3.43 mm long, exclusive of head, almost exactly twice as long as wide.

Front of head somewhat flattened, finely aciculate-punctate, punctures not conspicuous, with yellow incurved hairs (mostly abraded). Antenna yellowish, club elongate, nearly twice as long as wide, sutures sharply angulate. Eye elongate (21+5), widest above the broad shallow emargination.

Pronotum wider than long, posterior outline bisinuate; widest behind, sides arcuate and converging anteriorly; moderately constricted near anterior margin; surface smooth, shining, finely, moderately closely punctured, more coarsely at sides and in anterior constriction.

Elytra slightly wider than pronotum, sides feebly arcuate and convergent, separately rounded behind, emarginate in sutural region, not dehiscent, posterior border not serrate; surface moderately shining; striae with moderate punctures in definite rows, not at all or very feebly impressed, except at extreme base; interstrial punctures but little smaller; posterior sixth depressed and confusedly punctured.

Venter of abdomen very brightly shining, not strongly concave; anterior margin of second sternite evenly rounded as in *fagi*, not broadly, subtruncately rounded as in *quadrispinosus*; no true tubercles on any of the sternites but with slight indications of a median one on the fourth; fifth sternite longer than third and fourth combined, convex, with no elevated posterior margin, the median line indefinitely impressed.

Female.—Somewhat larger than male (3.23–4.34 mm long). Front of head convex, surface finely convergently aciculate, with fine inconspicuous punctures. Elytra as in male. Venter of abdomen with fifth segment much longer than in male, more strongly punctured, and with an elevated arcuate posterior margin.

Until within the last year no authentic specimen of *S. sulcatus* other than the type had been seen by the writer. In connection with the study of possible insect vectors of the Dutch elm disease, a single specimen was taken from elm by W. D. Buchanan at Chatham, N.J., on September 26, 1933, and three more at the same place on March 25, 1934. These specimens were all dead and partly disintegrated and were of the opposite sex from the unique type. A similar partly disintegrated female was taken on January 19, 1934, at Stamford, Conn., by J. A. Schmidt in connection with the work of the Federal Civil Works Administration. These females were all believed to be *S. sulcatus*, but until associated males were found their identity remained in doubt.

The identity of the species was established beyond a reasonable doubt by several series of specimens taken during the season of 1934. On June 7, A. E. Fivaz collected 4 females and 2 males from green elm bark at Maplewood, N.J., and on June 24 and 28 two other series from elm on Staten Island, N.Y. On July 24, D. O. Wolfenbarger also collected 2 females from elm bark at Yonkers, N.Y. But elm is

not the only host for *S. sulcatus*, for the writer has identified 2 specimens taken from plum at Greenwich, Conn., by F. J. Dillaway and 2 more collected from apple by Manigold at East Orange, N.J.

The fact that *S. sulcatus* has been found on several occasions in elm indicates that this shade tree is a favored, or at least a common, host for this bark beetle. If this is true, this species, until now of only taxonomic interest on account of its rarity, immediately acquires economic importance as a potential vector of the spores of *Graphium ulmi*, the fungus supposed to cause Dutch elm disease.

SCOLYTUS REFLEXUS, new species

Male.—Shining black with elytra piceous; 3.4 mm long, exclusive of head, about 2.4 times as long as wide.

Front of head flattened, subopaque, moderately coarsely aciculate-punctate, with yellowish-brown hairs of moderate length; well-developed epistomal process granulate-punctate, emargination narrower and somewhat deeper than usual, outer angles distinctly elevated. Eye elongate, wider above, broadly shallowly emarginate. Antenna light yellowish brown, club 1.3 times as long as funicle, 1.76 times as long as wide, slightly irregularly ovate, slightly wider distally to the middle, sutures moderately sharply angulate.

Pronotum 1.11 times as wide as long, posterior outline feebly bisinuate, posterior angles rounded, sides arcuate, rather strongly constricted near anterior margin, very broadly, subtruncately rounded in front; surface brightly shining, deeply and strongly, moderately closely punctured on disk, punctures at sides much coarser and those in anterior constriction very dense; posterior-lateral marginal line distinct and strongly elevated.

Elytra slightly narrower than pronotum, about 1.28 times as long as wide; humeri prominent, sides subparallel, feebly arcuate, posterior angles not serrate, broadly rounded, bisinuately emarginate in sutural region behind, scarcely or not at all dehiscent at suture; surface shining; scutellar region depressed as usual; striae often moderately strongly, but variably, impressed, punctures moderately fine and close; interspaces feebly or not at all impressed, punctures much finer; posterior sixth moderately depressed, punctures confused, coarser than on disk and moderately close.

Venter of abdomen brightly shining, moderately strongly punctured; first sternite convex behind, suture separating it from second sternite weakly elevated; second sternite somewhat oblique, nearly vertical, convex, punctures deep and strong, moderately numerous, with no evidence of a median tubercle; third and fourth sternites short as usual, hairs at sides longer, fourth slightly longer than third and with posterior margin weakly bisinuate; fifth sternite greatly modified, portion anterior to margin no longer than fourth, margin very strongly elevated in median region and drawn out to form a slightly recurved subrostriform ridge, portion posterior to margin vertical, more than twice as long as anterior division, finely and densely punctured.

Female.—Usual frontal differences. Elytral striae more strongly impressed, base subscabrous and posterior-lateral margin serrate. Venter similar to that of male, but fifth sternite as long as third and fourth combined, with posterior margin subangulate behind and not so strongly elevated.

Host.—Pseudotsuga taxifolia.

Type locality.—Santa Catalina Mountains, Ariz.

Type.—Catalog no. 43831, United States National Museum.

Type, allotype, and 11 paratypes (Hopkins U.S. 12210) collected at type locality by M. Chrisman; 7 paratypes (Hopkins U.S. 5625) collected at type locality by J. L. Webb; 1 paratype (1568) collected by Hubbard and Schwarz in the Chiricahua Mountains, Ariz., June 18.

SCOLYTUS WICKHAMI, new species

Male.—Shining black, with margins of pronotum and elytra piceous; 3.06 mm long, exclusive of head, about 2.12 times as long as wide.

Front of head flattened, moderately shining, finely aciculate, with rather fine punctures interspersed and with rather sparse and short yellowish hairs; epistomal process scarcely punctate, more narrowly and deeply emarginate than

usual, outer angles feebly elevated. Eye elongate, wider above, broadly and shallowly emarginate. Antenna yellowish brown, club 1.4 times as long as funicle, 1.5 times as long as wide, distinctly wider near distal end, sutures rather bluntly angulate.

Pronotum 1.1 times as wide as long, posterior outline feebly bisinuate, posterior angles rounded, sides weakly arcuate, very strongly constricted near anterior margin, subtruncate in front, subemarginate near median line; deeply, rather strongly, and closely punctured, more coarsely at sides and more coarsely and densely in anterior constriction; marginal line distinct and elevated, especially on sides.

Elytra very slightly wider than pronotum, about 1.22 times as long as wide; humeri prominent; sides feebly arcuate, very broadly conjointly rounded behind, not serrate, feebly dehiscent at suture, apex of each elytron notched opposite third interspace; surface brightly shining; scutellar region depressed; striae variably impressed (rather weakly in the type), punctures moderately fine, rather close (separated by less than their own diameter in first two striae); interspaces feebly or not at all impressed, punctures notably finer; caudal sixth moderately depressed, punctures confused, moderately close.

Venter of abdomen brightly shining, moderately strongly and closely punctured (more closely than in *reflexus*); first sternite nearly horizontal, separated from second by a more sharply elevated margin than in *reflexus*; second sternite nearly vertical and slightly convex, punctures deep, strong, and close, with no median tubercle; third and fourth sternites short, with longer hairs at sides, fourth with posterior margin feebly arcuate in median region; fifth sternite with portion anterior to margin but little longer than either of preceding segments, concave, margin strongly and sharply elevated (but not strongly extended in median region as in *reflexus*), portion posterior to margin vertical, but little longer than anterior part.

Female.—Frons convex, transversely impressed below; surface moderately shining, very finely, often obsoletely, aciculate and with evident, fine punctures; hairs sparse and short. Elytra serrate at sides and behind, very feebly subscabrous at base, more strongly punctured than in male type. Venter of abdomen similar to that of male, but last sternite about as long as third and fourth combined.

Host.—Pseudotsuga taxifolia.
Type locality.—Buena Vista, Colo. (7,900–8,000 feet).
Type.—Catalog no. 43832, United States National Museum.

Type and 4 paratypes collected at the type locality by H. F. Wickham, July 1–6, 1896; allotype and 12 paratypes (Hopkins U.S. 6354) collected at Fort Garland, Colo., and 7 paratypes (Hopkins U.S. 2304) collected at Tercio, Colo., by A. D. Hopkins; 2 paratypes (Hopkins U.S. 9902x) collected in North Cheyenne Canyon, Colo., by G. Hofer, reared May 22, 1914, by H. B. Kirk; 6 paratypes collected July 17, 1907 (Hopkins U.S. 5495), 2 paratypes (Hopkins U.S. 5486), and 13 paratypes collected in the Capitan Mountains, N.Mex., by J. L. Webb; 4 paratypes (Hopkins U.S. 2316a) collected at Vermejo, N.Mex., by A. D. Hopkins; 2 paratypes (Hopkins U.S. 5151) and 4 paratypes (Hopkins U.S. 5044b) collected in the San Francisco Mountains, Ariz., by J. L. Webb; 4 paratypes (Hopkins U.S. 21410g) collected July 24, 1930, and 29 paratypes (Hopkins U.S. 20421, c, d, e) collected July 29, 1930, in the Prescott National Forest, Ariz., by M. W. Blackman; 1 paratype collected July 27, 1923, in Montezuma National Forest, Ariz., by A. Hough; 3 paratypes (Hopkins U.S. 4558p) collected at Kamas, Utah, by H. E. Burke.

This species is more closely allied to *reflexus* than to any other, but the males can be readily distinguished not only by the abdominal characters but by the frontal and elytral characters as well. The separation of the females is more difficult, but the elytra in *reflexus* are more strongly roughened at the base, the second sternite has a less definite anterior margin, and the second and fifth sternites are less closely punctured.

SCOLYTUS TSUGAE Swaine

Male.—Shining black; 2.7 to 3.4 mm long, exclusive of head, about 2.12 times as long as wide.

Front of head slightly convex; epistomal process wide, moderately strongly, broadly emarginate; surface moderately shining, very finely aciculate, with numerous deep, fine punctures, bearing rather short, yellowish hairs. Eye elongate, only slightly wider above the broad shallow emargination. Antenna yellowish brown, club 1.46 times as long as funicle, 1.43 times as long as wide, irregularly oval, widest just distad of the middle, sutures angulate.

Pronotum wider than long, posterior outline nearly straight, rounded at posterior angles, sides arcuate, rather strongly constricted near anterior margin, anterior outline broadly rounded, feebly and broadly emarginate in median area; surface brightly shining, finely, deeply, moderately closely punctured on disk except on median line, which is sparsely or not at all punctate; sides somewhat coarsely and anterior constriction more densely punctured; posterior lateral marginal line fine and distinctly elevated.

Elytra scarcely wider than pronotum, about 1.24 times as long as wide; humeri moderate, sides arcuate, feebly converging posteriorly, broadly, conjointly rounded, margin obsoletely serrate, dehiscent at suture; surface brightly shining; scutellum wider than long, depressed; striae usually strongly, but variably, impressed, punctures moderate in size and spacing; interspaces feebly and variably impressed, with finer and sparser punctures, caudal sixth moderately depressed, with coarser, confused punctures.

Venter of abdomen opaque or subopaque; second sternite vertical, bordered anteriorly by a fine, moderately elevated margin, punctures moderately close and fine; third and fourth sternites short, more finely punctured; fifth sternite shorter than preceding two combined, rather deeply concave, with a strongly and sharply elevated, arcuate, posterior margin.

Female.—Similar to male, but frons convex, with surface smoother, scarcely aciculate, more sparsely and finely punctured, and with fewer hairs. Elytra feebly scabrous at base and finely serrate on posterior-lateral margin. Venter wider, with fifth sternite usually slightly longer than third and fourth combined.

This species was described by Swaine from specimens collected in British Columbia and Alberta from *Tsuga mertensiana* and *Pseudotsuga mucronata* (= *taxifolia*). The writer has studied the types. Additional specimens assigned to this species, all from *T. mertensiana*, are from Washington, Oregon, and California.

SCOLYTUS MONTICOLAE Swaine

Male.—Shining black, often with elytra reddish brown; 2.2 to 2.8 mm long, exclusive of head, about 2.1 times as long as wide.

Front of head flattened, epistomal process broadly and shallowly emarginate; surface feebly shining, finely but distinctly aciculate-punctate, with numerous moderately short, yellowish hairs. Eye elongate, distinctly wider above the broad, shallow emargination. Antenna yellowish brown, club 1.41 times as long as funicle, 1.58 times as long as wide, irregularly oval, slightly wider distally to the middle, sutures moderately angulate.

Pronotum distinctly wider than long, widest just behind middle; posterior margin nearly straight, feebly bisinuate, posterior angles rounded; sides distinctly arcuate, moderately strongly constricted near anterior margin; anterior outline broadly rounded; surface shining, moderately finely, deeply, rather closely punctured, more sparsely in median line, punctures coarser at sides and denser in constriction; marginal line at sides and behind fine but distinct.

Elytra scarcely wider than pronotum, about 1.24 times as long as wide; sides nearly straight; broadly conjointly rounded behind, many specimens notched at apex opposite third interspace; feebly dehiscent at suture, margin not serrate; surface brightly shining; scutellum wider than long, moderately depressed; striae usually weakly, but variably, impressed, punctures rather fine, not close; interspaces usually not impressed, punctures very fine; caudal sixth moderately strongly depressed, more coarsely, closely, confusedly punctured.

Venter of abdomen with second sternite vertical, finely margined in front, surface moderately to brightly shining, finely, moderately sparsely punctured; second and third sternites subopaque to feebly shining, fifth shorter than third and fourth combined, concave, with a strong, sharply elevated, arcuate caudal margin.

Female.—Front convex, surface smoother, and punctures and hairs sparser. Base of elytra feebly scabrous, and posterior-lateral margins finely serrate. Venter of abdomen with second sternite more feebly margined in front and slightly oblique on posterior fourth; fifth sternite longer than third and fourth combined, concave and margined as in male.

This form is very closely allied to *Scolytus tsugae* and specimens assigned to *monticolae* are sometimes found in field series of *tsugae*. Also there are many intergradations between the more coarsely sculptured forms with the ventral abdomen opaque which are representative of *tsugae* and the more smoothly sculptured *monticolae* with the venter shining. The writer is somewhat at a loss in definitely assigning certain of these intermediate forms to either species.

Scolytus monticolae was described by Swaine from specimens taken in British Columbia from *Pinus monticola* and *Pseudotsuga mucronata* (= *taxifolia*). The types have been studied by the writer. Additional specimens assigned to this species are from Oregon, Washington, Idaho, Montana, and Wyoming. The trees serving as hosts were *Pseudotsuga taxifolia*, *Tsuga mertensiana*(?), *Abies grandis*, and *Abies* sp.

SCOLYTUS QUADRISPINOSUS Say **(S. CARYAE** Riley)

Male.—Shining black, with elytra varying from reddish brown to black; ranging in length from 2.9 to 5.0 mm exclusive of head, about twice as long as wide.

Front of head very broadly flattened, slightly concave; coarsely, longitudinally aciculate with sparse, laterally compressed punctures interspersed; ornamented with long brown hairs, rather fine and sparse except for dense border of coarser, longer, incurved hairs; epistomal process strongly elevated at sides, broadly, moderately deeply emarginate. Eye elongate (7+24), wider above, inner line shallowly emarginate. Antenna yellowish brown, club 1.5 times as long as funicle, 1.18 times as long as wide, distinctly wider distally, sutures angulate.

Pronotum slightly wider than long, widest just behind middle, posterior outline bisinuate, sides convergently arcuate, constricted near anterior margin, broadly, subtruncately rounded in front; surface shining, disk finely, moderately sparsely punctured, more coarsely and closely at sides and more densely in anterior constriction; disk glabrous, with rather long yellowish hairs at anterior lateral angles and in front; posterior margin fine but distinct, that at sides stronger.

Elytra about equal in width to pronotum, the length scarcely exceeding the width; sides nearly straight and subparallel on anterior half, convergently arcuate, very broadly, subtruncately rounded behind, with posterior lateral margin strongly serrate; surface shining, strongly depressed in scutellar region; humeri weakly elevated; striae very strongly impressed, punctures coarse and close, smaller near the base; interspaces finely and much more weakly impressed, punctures fine; striae extending nearly to extreme apex and only caudal fifteenth of elytra weakly depressed.

Venter of abdomen very strongly concave; second sternite deeply excavated, anterior margin very strongly produced, with a subacute, strongly recurved process in median line, its posterior face with dense, short hairs; surface opaque, minutely, obsoletely punctured, with a distinct acute median carina, posterior margin usually with a sharp toothlike elevation at each lateral angle; third sternite short, minutely punctured, with three prominent spines, a heavy one at each posterior lateral angle and a more slender one in median line on posterior margin; fourth sternite more strongly punctured, concave, caudal margin sharply elevated, with a sharp median spine (variable in its development), also often with a toothlike elevation at each lateral angle; fifth sternite very short, less than one-third as long as fourth, densely punctured, with rather fine, dense, and short pubescence on its posterior vertical face.

Female.—Frons less broadly and strongly flattened, subconvex, more finely aciculate, with hairs shorter and less numerous but similarly arranged. Venter with second abdominal sternite subvertical, opaque, finely punctured, with fine, short, erect hairs; third sternite short, finely punctured; fourth similar but more strongly punctured; fifth as long as last two together, more coarsely and closely punctured, posterior face with dense short pubescence.

Scolytus quadrispinosus shows considerable variation in the sculpture of the frons, pronotum, elytra, and abdomen. This is especially true of the males, those from the Southern States showing a distinct tendency toward the stronger development of the ventral spines. This usually involves a greater development of the tubercles at the posterior-lateral angles of the second sternite, thus forming a six-spined venter. In two males, however, both from Mississippi, there is an additional long slender spine arising from the second sternite near the posterior margin just at the left of the median carina.

Several thousand specimens of *Scolytus quadrispinosus*, including the type series of *S. caryae* Riley, have been studied by the writer. These include specimens from Connecticut, New York, New Jersey, Pennsylvania, Ohio, Michigan, Wisconsin, Iowa, Missouri, Kansas, Illinois, Indiana, Tennessee, West Virginia, Virginia, the District of Columbia, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Louisiana, and Texas. Swaine also reports it from Utah, Quebec, and Ontario.

The host trees include all species of the genus *Hicoria* occurring in its range, including native and cultivated pecans. The writer has also seen the beetles beginning an attack upon butternut trees (*Juglans cinerea*).

SCOLYTUS SUBSCABER Leconte

Female.—Shining black; 4.0 mm long exclusive of head, about twice as long as wide.

Front of head transversely impressed just behind elevated, broadly and shallowly emarginate epistomal process; convex between eyes, flattened and slightly impressed above upper angle of eye; strongly aciculate above, more feebly below, with interspersed punctures from which arise erect hairs of moderate length. Eye rather finely granulate, elongate, wider above, inner line broadly and moderately shallowly emarginate. Antenna light brown, club 1.6 times as long as wide, wider distally, sutures sharply angulate.

Pronotum wider than long, widest just behind middle; posterior outline bisinuate, nearly straight; sides arcuate, rather strongly constricted near anterior margin; surface shining, with disk finely, obsolescently punctate, punctures coarser and closer in anterior constriction; marginal line fine behind, strongly elevated and coarser at sides.

Elytra wider than pronotum, sides subparallel, feebly arcuate; separately rounded behind, apex feebly emarginate in median region, feebly dehiscent at sutures, margin weakly, finely serrate; surface shining, scabrous at the base; strial punctures moderately fine behind but larger toward base, striae not strongly impressed, but often with very fine impressed lines at one or both sides of strial row; interstrial punctures scarcely finer; punctures both of striae and interspaces often with anterior margins slightly elevated (muricate), especially on anterior third; posterior sixth rather strongly depressed, densely, rugosely punctured.

Venter of abdomen with first sternite horizontal, punctures moderate, with semierect, backwardly directed yellowish hairs; second sternite opaque or subopaque, nearly vertical, convex, anterior margin fine and not conspicuous, punctures moderately coarse, rather sparse, with no evidence of a median tubercle; third and fourth sternites short, together much shorter than fifth, punctures minute, rather close; fifth sternite somewhat concave, bordered posteriorly by a very strongly elevated, acute, arcuate margin, finely punctured, with a faint, rather indefinite median longitudinal elevation, not a definite carina.

The foregoing description is taken entirely from the type. The type is from Vancouver, British Columbia. Four other specimens from Oregon and California are *Scolytus ventralis*, 2 of them, marked types, being females and the other 2 males.

Aside from the type specimen, the writer has examined more than a dozen specimens of females and nearly as many males, all collected in California by J. M. Miller. Two of these specimens, all that were

in the possession of the writer at the time, were compared directly with the type, which is a female, and found to be identical except for slight individual differences. The series shows the usual range of variation in size and sculpture. The length, exclusive of the head, ranges from 2.88 mm to 4.44 mm; other variations have to do with the size of the punctures on the pronotum, elytra, and abdominal sternites, with the degree to which the elytra show the scabrous or subscabrous condition, and with the shape of the second abdominal sternite, the larger specimens usually having this segment relatively wider.

Male.—From 3 to 4 mm long, not quite twice as long as wide; shining black in color, allied to *Scolytus praeceps*. Front of head broadly flattened from eye to eye; epistomal process prominent, broadly emarginate, more deeply than in female, surface coarsely aciculate-punctate, with rather coarse brownish hairs of moderate length. Pronotum about 1.18 times as wide as long, similar to that of female in shape and sculpture. Elytra similar to those of female except that they are not at all scabrous and the posterior-lateral outline is scarcely or not at all serrate. Venter of abdomen very different, surface opaque and very finely punctured; second sternite bordered anteriorly by a strongly elevated and moderately thick, extended margin, surface opaque, with sparse, very fine, obscure punctures, with a median carinal tubercle on posterior margin; third and fourth sternites short, finely, moderately closely punctured; fifth sternite longer than third and fourth combined, with a strongly elevated, arcuate posterior margin, somewhat concave but with the median area convex, surface opaque, with moderately numerous, fine punctures.

SCOLYTUS OREGONI, new species

Male.—Shining black, elytra piceous; 3.20 mm long, about twice as long as wide.

Front of head flattened well behind the eyes; epistomal process broad, elevated at sides, broadly, rather deeply emarginate; surface moderately finely aciculate, with conspicuous, deep punctures, bearing numerous rather long, moderately fine, yellowish-brown hairs. Eye elongate, notably wider above, inner line broadly and shallowly emarginate. Antenna light yellowish brown, club 1.22 times as long as funicle, 1.7 times as long as wide, irregularly oval, scarcely wider distally to middle, sutures moderately sharply angulate.

Pronotum 1.16 times as wide as long, widest at about middle; posterior outline feebly bisinuate; sides arcuate, distinctly constricted near anterior margin; anterior outline broadly, feebly emarginate; surface shining, with numerous small, rather deep punctures, becoming coarser at sides and in front; posterior and lateral marginal line distinct and strongly elevated.

Elytra slightly wider than pronotum, 1.19 times as long as wide, with humeri prominent; sides feebly arcuate, posterior lateral angles broadly rounded, margin scarcely serrate, dehiscent at suture, with each elytron slightly extended in sutural area; surface moderately shining, scutellar region depressed; striae and interspaces weakly, nearly equally impressed, punctures rather fine and but little finer on interspaces; caudal sixth moderately depressed, confusedly, more coarsely punctured.

Venter of abdomen shining; second sternite vertical, narrowly rounded in front, separated from first by a thick, elevated, and moderately extended margin, with fairly numerous, deep, moderately fine punctures, posterior margin usually with faint trace of a median tubercle; third and fourth sternites short, more deeply punctured; fifth sternite considerably shorter than third and fourth together, concave, with an evenly arcuate, sharply elevated posterior margin.

Female.—Usual secondary sexual differences, with frons transversely impressed below, convex above, finely aciculate-punctate with scantier and shorter hairs. Elytra distinctly but finely scabrous at base, tip finely but evidently serrate. Second abdominal sternite oblique, similar to that of male but less strongly margined in front and with no evidence of a median tubercle; fifth sternite longer than third and fourth combined.

Hosts.—*Pseudotsuga taxifolia* and *Abies concolor*.

Type locality.—Ashland, Oreg.

Type.—Catalog no. 43834, United States National Museum.

Type, allotype, and 15 paratypes (Hopkins U.S. 13399a) collected at the type locality by W. E. Glendenning, February 3, 1919; other

paratypes from the type locality include 6 collected by W. E. Glendenning under Hopkins U.S. 13363b and 4 collected by P. D. Sargent under Hopkins U.S. 14246c; 1 paratype (Hopkins U.S. 63) collected by Hopkins from *Abies concolor* at Grants Pass, Oreg.

SCOLYTUS ROBUSTUS. new species

Male.—Shining black, elytra very dark reddish brown; 3.41 mm long, less than twice as long as wide.

Front of head strongly flattened well behind eyes; epistomal process broad, low, margin rather deeply emarginate; surface moderately shining, strongly aciculate-punctate, and ornamented with fine, brown hairs of moderate length. Eye finely granulate, elongate, considerably wider above, inner line broadly and shallowly emarginate. Antenna yellowish brown, club 1.27 times as long as funicle, 1.68 times as long as wide, irregularly oval, slightly wider just distad of middle, sutures sharply angulate.

Pronotum 1.15 times as wide as long, widest well behind middle; posterior outline feebly bisinuate, posterior angles rounded; sides feebly arcuate, suddenly constricted near anterior border, anterior outline subtruncate; surface brightly shining; glabrous, strongly, deeply, rather closely punctured on disk, more coarsely and closely on sides and in anterior constriction; posterior and lateral marginal line strongly elevated.

Elytra slightly wider than pronotum, about 1.1 times as long as wide; sides subparallel (feebly arcuate), broadly rounded at posterior angles, posterior lateral margin variably, finely serrate; subtruncate behind, very feebly dehiscent at suture; surface shining, scutellar region depressed; striae variably, usually weakly, impressed, punctures deep and strong, not coarse, moderately numerous; interspaces usually not impressed, punctures slightly finer; posterior sixth rather weakly depressed, densely, confusedly punctured.

Venter of abdomen brightly shining; second sternite strongly concave, bordered anteriorly by a strongly elevated, rather thick, liplike margin, strongly, coarsely, rather closely punctured, posterior margin with little or no indication of a median tubercle; third and fourth sternites short, more finely punctured; fifth sternite longer than third and fourth together, more coarsely punctured than preceding two but more finely than second, concave, with a strongly elevated, evenly arcuate posterior margin.

Female.—Similar in general characters, but frons convex, more finely aciculate-punctate, and with shorter and more scanty hairs. Elytra scabrous at base, and posterior-lateral margins distinctly serrate. Anterior margin of second sternite strongly elevated but less strongly extended, more coarsely punctured, and fifth sternite longer.

Hosts.—*Abies concolor, A. lasiocarpa, Pseudotsuga taxifolia.*
Type locality.—Prescott, Ariz.
Type.—Catalog no. 43835, United States National Museum.

Type and 10 paratypes (Hopkins U.S. 20410e) collected July 24, 1930, at the type locality by M. W. Blackman; allotype and 5 paratypes (Hopkins U.S. 9903x) collected at Colorado Springs, Colo., by B. T. Harvey; 5 paratypes (Hopkins U.S. 12244a) reared at Williams Canyon, Colo., by W. D. Edmonston; 5 paratypes (Hopkins U.S. 3951) collected in the Capitan Mountains, N.Mex., by W. F. Fiske; 11 paratypes collected in the Santa Catalina Mountains, Ariz., by J. L. Webb; 4 paratypes (Hopkins U.S. 5666) collected in the Capitan Mountains, N.Mex., by J. L. Webb; 10 paratypes (Hopkins U.S. 11910) collected in El Paso County, Colo., by W. D. Edmonston; 13 paratypes collected in Kaibab National Forest, Ariz., by M. W. Blackman. All the above were taken from *Abies concolor.* In addition, 1 paratype (Hopkins U.S. 4548a) collected from *A. lasiocarpa* at Kamas, Utah, by H. E. Burke; 1 paratype (Hopkins U.S. 3991) collected from *Pseudotsuga taxifolia* at Cloudcroft, N.Mex., by W. F. Fiske.

SCOLYTUS PRAECEPS Leconte

Female.—Black, moderately shining, with elytra reddish brown; 3.0 mm long, about 2.21 times as long as wide.

Front of head convex; epistomal process wide, low, broadly emarginate; surface rather finely aciculate, with rather conspicuous, deep punctures of moderate size, bearing fine, yellowish hairs of moderate length. Eye elongate, slightly wider above, inner line broadly emarginate. Antenna yellowish, club 1.28 times as long as funicle, 1.6 times as long as wide, irregularly oval, widest just distad of middle, sutures angulate.

Pronotum slightly wider than long (46.5:42), widest just behind middle; sides arcuate, moderately constricted near anterior margin; surface shining; punctures deep, moderately fine, and rather numerous, much coarser on sides, and denser in anterior constriction; marginal line distinct behind and more so at sides.

Elytra slightly wider than pronotum, 1.12 times as long as wide; sides subparallel, broadly rounded and feebly emarginate behind, slightly dehiscent at suture, posterior-lateral margin finely, irregularly serrate; moderately depressed about scutellum; surface shining, rather weakly subscabrous at base; striae variably impressed, impressed lines not always corresponding with either striae or interspaces, strial punctures of moderate size, coarser toward base, and separated by more than their own diameter; punctures of interspaces slightly finer; posterior sixth weakly depressed, densely and confusedly punctured.

Venter of abdomen with surface opaque; second sternite nearly perpendicular, separated from first by a well-developed, elevated, acute margin, punctures moderate in size and arrangement, with very fine, short, reclinate hairs, posterior border with a very feeble, scarcely visible, carinal tooth; third and fourth sternites short, opaque, often darker in color, very finely and more closely punctured; fifth sternite longer than third and fourth combined, opaque, very finely punctured, concave, with a sharply elevated, arcuate posterior margin.

Male.—Similar to female but having frons flattened between eyes, more coarsely aciculate-punctate, with coarser, longer, and more numerous hairs; epistomal process more prominent; base of elytra not subscabrous; second abdominal sternite subopaque, more strongly punctured, with anterior margin thicker, strongly elevated, and extended; median carinal tooth more elevated and sometimes with a carinal elevation extending nearly to center of sternite; fifth sternite shorter.

The description of the female is taken from the type.

Specimens of this species have been studied from California, Arizona, New Mexico, and Texas. The host trees are species of *Abies*, especially *A. concolor*.

SCOLYTUS OPACUS, new species

Male.—Shining black, with elytra dark reddish brown; 2.77 mm long, exclusive of head, about twice as long as wide; closely allied to *Scolytus abietis* but larger.

Front of head sloping, flattened on area extending well behind eyes, moderately finely aciculate-punctate, with rather short yellowish-brown hairs; epistomal process low, rather broadly, shallowly emarginate. Eye elongate, considerably wider above, inner line shallowly emarginate. Antenna yellowish brown, club 1.42 times as long as funicle, 1.64 times as long as wide, slightly irregularly oval, widest at about middle, sutures moderately angulate.

Pronotum 1.15 times as wide as long, widest at about middle; posterior outline feebly sinuate, sides arcuate, distinctly constricted near anterior margin, very broadly, subtruncately rounded in front; surface moderately shining, glabrous on disk; punctures deep, moderate in size and distribution, coarser and closer on sides, and denser in anterior constriction; posterior marginal line distinct, that on sides more strongly elevated.

Elytra wider than pronotum, about 1.16 times as long as wide, widest at about the middle, with sides weakly arcuate, individually rounded behind and shallowly emarginate in sutural region; posterior-lateral margin finely, irregularly serrate; surface moderately shining, glabrous on disk; striae, except first two, feebly or not at all impressed, punctures fine, not close; interspaces with punctures but little finer than those of striae, not impressed; caudal portion moderately strongly depressed, with punctures dense and confused.

Venter of abdomen with second sternite concave, bordered anteriorly by a strongly elevated, liplike margin, surface subopaque, punctures very fine and sparse, with a wide, strongly elevated, blunt carina extending from posterior margin to a point well in front of the center, where it is strongly extended to form a conspicuous, well-developed, blunt spine; remaining sternites opaque, very finely, moderately closely punctured, fifth as long as preceding two combined, concave, with a strongly and sharply elevated, arcuate posterior margin.

Female.—A form believed to be the female of this species is similar in general characters, with frons convex, transversely impressed just above epistomal margin, finely aciculate and with moderately fine punctures bearing short dark brown hairs; pronotum more finely punctured; elytra feebly subscabrous at base; venter opaque; second sternite bordered anteriorly by a liplike margin nearly as strong as in male, with a feebly elevated blunt median carina extending from posterior margin to middle; posterior sternites all longer than in male, fifth considerably longer than third and fourth together.

Host.—Abies lasiocarpa.

Type locality.—Ouray, Colo.

Type.—Catalog no. 43836, United States National Museum.

Type and 1 paratype collected in July 1897 at Ouray, Colo., at an elevation of 7,500–8,000 feet by H. F. Wickham; allotype and 2 paratypes (Hopkins U.S. 16973a) collected in Glacier National Park, August 24, 1923, by J. C. Evenden; 1 paratype collected July 18 at Brightons, Utah, by Hubbard and Schwarz.

SCOLYTUS ABIETIS, new species

Male.—Dark reddish brown, nearly black, with elytra lighter in color; 2.0 to 2.4 mm long (type 2.1 mm) exclusive of head, nearly exactly twice as long as wide.

Front of head flattened on an area extending to just back of eyes, convex above, feebly concave below; epistomal process widely and shallowly emarginate; surface finely aciculate-punctate, with fine, long, light yellow hairs. Eyes elongate, inner line feebly emarginate. Antenna much lighter in color, club 1.32 times as long as funicle, 1.66 times as long as wide, irregularly oval, widest near middle, suture rather broadly angulate.

Pronotum 1.13 times as wide as long, widest near posterior border; posterior outline nearly straight; sides feebly, convergently arcuate, strongly constricted near anterior margin; surface shining, glabrous on disk, punctures moderately fine, much coarser on sides and denser in anterior constriction; marginal line distinct on sides and behind.

Elytra slightly wider than pronotum, about 1.16 times as long as wide; nearly straight and subparallel at sides, individually rounded behind and shallowly emarginate in sutural region, margin behind irregularly, finely serrate; surface moderately shining, glabrous on disk; striae, aside from the first two, feebly or not at all impressed, punctures moderately fine, moderately close; interspaces more finely and sparsely punctured; caudal portion moderately depressed, with punctures very dense, confused, some of them bearing setae.

Venter of abdomen with second sternite concave and bordered anteriorly by a strongly elevated, rather thick, liplike margin, surface moderately shining, punctures sparse and moderately fine, with a wide, strongly elevated, blunt carina extending from posterior margin to a point well in front of center and most strongly elevated anteriorly where it is sometimes extended to form a short, blunt spine; third and fourth sternites short, subopaque, very finely and closely punctured; fifth sternite nearly as long as third and fourth combined, concave, with a strongly elevated, arcuate posterior margin.

Female.—Front of head convex, transversely impressed below, finely aciculate-punctate, with the fine hairs shorter than in male. Base of elytra weakly scabrous. Second abdominal sternite less strongly margined anteriorly, with median carina much more feebly developed and usually extending scarcely to center of segment; fifth sternite longer than third and fourth combined.

Host.—Abies grandis.

Type locality.—Sandpoint, Idaho.

Type.—Catalog no. 43837, United States National Museum.

Type, allotype, and 21 paratypes (Hopkins U.S. 224) were taken at the type locality, June 20, 1899, by A. D. Hopkins; 5 paratypes (Hopkins U.S. 222) taken by the same collector at the type locality

June 2, 1899; 1 paratype collected by Wickham at Coeur d'Alene, Idaho; 6 paratypes (Hopkins U.S. 16952a) collected at Coeur d'Alene, Idaho, by H. J. Rust.

SCOLYTUS VENTRALIS Leconte

Male.—Shining black, with elytra reddish brown; 3.71 mm long exclusive of head, about twice as long as wide.

Front of head somewhat flattened; epistomal process wide, outer angles elevated, broadly, fairly deeply emarginate; surface moderately coarsely aciculate-punctate, often with a median longitudinal smooth area on epistoma; hairs yellowish brown, moderate in number and length. Eye elongate, much wider above, inner line feebly, very broadly emarginate. Antenna yellowish brown, club 1.3 times as long as funicle, 1.65 times as long as wide, irregularly ovate, wider near distal end, sutures angulate.

Pronotum wider than long, widest at about the middle; posterior outline feebly bisinuate; sides distinctly arcuate, strongly constricted near anterior margin, anterior outline very broadly subtruncately rounded; surface smooth, shining, punctures on disk rather fine, moderately numerous, much coarser on sides and coarser and closer in anterior constriction; marginal line fine but distinct behind, much stronger at sides.

Elytra slightly wider than pronotum, sides subparallel (feebly arcuate), broadly, conjointly rounded behind, posterior-lateral margin finely serrate; dehiscent at suture; surface shining; striae feebly and variably or not at all impressed, punctures moderately fine, not close, slightly coarser toward base; interspaces with slightly finer punctures; caudal sixth moderately depressed, closely, rugosely punctured, with a few setae.

Venter of abdomen opaque or subopaque; second sternite nearly vertical, strongly margined anteriorly, convex in median area, moderately finely and sparsely punctured, posterior margin with a sharp, elevated, median carinal tubercle; third and fourth sternites short, more finely and closely punctured; fifth sternite nearly as long as third and fourth combined, concave, with a very strongly elevated, evenly arcuate, acute posterior margin.

Female.—Frons convex above, transversely impressed just above epistomal margin, with a short, elevated, median carina bridging the impression; surface moderately finely punctured and weakly aciculate, with short sparse hairs. Elytra scarcely scabrous at base, more strongly serrate on posterior-lateral margin. Venter opaque or subopaque; second sternite more convex in median area, more weakly margined anteriorly, and with only faint traces or none at all of median tubercle; fifth sternite longer than third and fourth combined.

The description of the male, with the exception of the details of antennal structure, is taken entirely from the type.

Specimens of this species studied by the writer were collected in British Columbia, Washington, Oregon, California, Idaho, Montana, Utah, Arizona, and New Mexico. The hosts are *Abies concolor, A. grandis, A. lasiocarpa, Pseudotsuga taxifolia, Picea engelmannii* (one lot), and *Tsuga mertensiana.* The species is not only widely distributed but variable in certain characters. The specimens from Utah, Arizona, and New Mexico usually have the venter of the abdomen more opaque and more coarsely punctured than those occurring in the Pacific Coast States.

SCOLYTUS (CALIFORNICUS Leconte) [1] SCOLYTUS (Fabricius)

Female.—Pronotum shining black, elytra reddish brown; 4.0 mm long exclusive of head, about 2.18 times as long as wide.

Front of head convex, transversely impressed above the elevated, emarginate epistomal process, slightly flattened well above the eyes, finely densely granulate-punctate in median area, more coarsely punctured toward sides, with very fine, short, erect hairs (mostly abraded in type). Eye elongate, widest above, inner line broadly, rather shallowly emarginate. Antenna not present beyond second joint of funicle.

[1] New synonymy.

Pronotum slightly wider than long, widest posteriorly; posterior outline bisinuate, sides arcuate, distinctly narrowed anteriorly, rather weakly constricted near anterior margin, anterior outline broadly, shallowly emarginate; surface smooth, shining, punctures at center of disk fine, but becoming coarser and deeper laterally and anteriorly; marginal line distinct.

Elytra slightly wider than pronotum, sides feebly arcuate and converging posteriorly; separately rounded behind and emarginate in the sutural region, not dehiscent at suture; surface moderately shining, striae distinct, rather strongly impressed, punctures moderately coarse and close; interspaces wide, confusedly punctured in second and third interspaces; posterior sixth depressed, with punctures confused, coarser, some of them bearing setae.

Venter of abdomen shining, rather finely but deeply and densely punctured; first sternite convex, with very fine, moderately long hairs (mostly abraded); second sternite oblique, convex with a faint median carina; third and fourth sternites short, each with a distinct rather sharp tubercle at middle of posterior margin; fifth sternite longer than third and fourth together, somewhat impressed in median line, with a strongly elevated, posterior margin.

The foregoing description was prepared from Leconte's type of *Scolytus californicus*, but as the description was written it was compared point by point with authentic specimens of *S. scolytus* from France, Germany, and Russia. The agreement, not only in general characters but in all essential details of structure, with the females of *S. scolytus* is complete. It seems probable, therefore, that this specimen received by Leconte from Andrew Murray was incorrectly labeled as to its source. No other specimen even approaching it in structure has been seen from North America.

A second specimen in the Leconte collection labeled "*S. californicus*" but not mentioned by Leconte is a male of *S. oregoni*.

While it is not known that *Scolytus scolytus* has become established in this country, it is by no means improbable that it has or, if not now established, that it will soon become so. During the summer of 1933 numerous interceptions of both this species and *S. multistriatus* were made in shipments of elm logs from France. These logs, many of which were heavily infected with the Dutch elm disease, were also heavily infested with *S. scolytus* in all stages and also with the smaller elm bark beetle (*S. multistriatus*) and with *Pteleobius kraatzi* Eichh., another bark beetle attacking elm.

SCOLYTUS SOBRINUS, new species

Male.—Shining, piceous black, elytra dark reddish brown; 2.65 mm long, about 2.07 times as long as wide.

Front of head slightly convex, on an area extending only slightly behind eyes, transversely impressed above the low, broad epistomal process; surface shining, finely aciculate-punctate (slightly more coarsely than in *unispinosus*), with moderately long, slender, yellowish-brown hairs. Eye elongate, wider above, inner line very broadly and shallowly emarginate. Antenna testaceous, club 1.35 times as long as funicle, 1.5 times as long as wide, irregularly oval, widest at about the middle, suture rather broadly angulate.

Pronotum slightly wider than long, widest behind middle, posterior outline bisinuate; sides distinctly arcuate, constricted near anterior margin, which is very feebly and broadly emarginate; surface brightly shining, piceous except in anterior constriction; moderately finely, not densely punctured, more densely on sides and in anterior constriction; glabrous except at sides and in front; marginal line sharp and distinct on both posterior and lateral margins.

Elytra slightly wider than pronotum, about 1.2 times as long as wide; sides subparallel (very feebly arcuate), broadly conjointly rounded behind; hind margin not serrate, feebly dehiscent at suture; surface shining; striae usually strongly (but variably) impressed, punctures moderately fine (coarser than in either *unispinosus* or *laricis*, rather distant, deep; interspaces not impressed, punctures finer and rather distant; caudal area moderately depressed, punctures confused, rather close, some bearing setae.

Venter of abdomen subopaque; second sternite not strongly margined anteriorly, nearly vertical, convex, punctures very fine and sparse, with a conspicuous, stout, blunt spine, apex circular, but base compressed and usually extending from posterior margin nearly or quite to center of sternite; third and fourth sternites short, opaque, minutely punctured; fifth not quite so long as preceding two combined, opaque, minutely punctured, concave, with a strongly elevated, subarcuate posterior margin.

Female.—Front of head transversely impressed just above epistomal margin, strongly convex, with sparser and shorter hairs. Base of elytra finely subscabrous, posterior-lateral margin finely serrate. Second sternite bearing a sharp, conical, median tubercle.

Host.—*Pseudotsuga taxifolia.*
Type locality.—Kent, Wash.
Type.—Catalog no. 43838, United States National Museum.

Type, allotype, and 4 paratypes (Hopkins U.S. 4190a) collected at the type locality by H. E. Burke; 24 paratypes bearing identical data except for different lot numbers; 6 paratypes (Hopkins U.S. 14238b) collected at Little Applegate River, Oreg., by J. E. Patterson; 3 paratypes (Hopkins U.S. 14264t) collected in flight at Ashland, Oreg., by F. P. Keen; 5 paratypes (Hopkins U.S. 6107) taken at Jackson, Wyo., by A. D. Hopkins.

This species is closely related to *Scolytus unispinosus* and *S. laricis*. It differs from both, however, in the frontal characters, in the punctation of both pronotum and elytra, and in the structure of the abdominal sternites.

SCOLYTUS LARICIS, new species

Male.—Shining black with the elytra dark reddish brown to black, 2.0 to 2.6 mm long (type 2.37 mm), exclusive of head, about 2.1 times as long as wide; similar to *Scolytus unispinosus* but usually larger, more coarsely punctured, and differing in frontal and abdominal characters.

Front of head strongly flattened and slightly concave on area extending well behind eyes, strongly punctured and rather coarsely aciculate, often converging to meet a slightly elevated median longitudinal carina, ornamented with numerous moderately coarse, rather long, yellowish-brown hairs; epistomal process broad, rather low, broadly, moderately deeply emarginate. Eye elongate, very broadly, rather shallowly emarginate in front. Antenna yellowish brown, club 1.33 times as long as funicle, 1.77 times as long as wide, irregularly oval, widest distally to middle, sutures rather broadly angulate.

Pronotum 1.11 times as wide as long, widest just behind the middle; sides distinctly arcuate, distinctly constricted near anterior margin, surface shining, moderately finely and closely punctured, glabrous except at anterior and lateral borders; posterior marginal line distinct, more strongly elevated at sides.

Elytra slightly narrower than pronotum, 1.22 times as long as wide; sides subparallel (feebly arcuate), broadly, conjointly rounded behind, hind margin not serrate, scarcely at all dehiscent at suture; surface shining, glabrous except at sides and in posterior depression, moderately deeply impressed near scutellum, striae variably impressed on disk, punctures moderately fine, deep (distinctly coarser and slightly closer than in *unispinosus*); interspacial punctures finer; caudal portion moderately depressed, punctures here and on sides numerous, deep, close, and not regularly arranged, with numerous setae.

Venter of abdomen with second sternite feebly shining, convex, not so nearly vertical as in *unispinosus* and more strongly margined anteriorly, punctures deep, moderately fine, with the very conspicuous median spine much stouter than in *unispinosus*, strongly compressed from base to apex, with base extending from caudal margin nearly or quite three-fourths of length of segment; remaining sternites subopaque, short, finely punctured, fifth concave with a strongly elevated, subangulate posterior margin, considerably shorter than third and fourth combined.

Female.—Front subconvex, slightly flattened in front, finely punctate-aciculate, and with finer and shorter hairs. Elytra with base somewhat scabrous and striae more strongly impressed. Second ventral segment broader, and with spine replaced by a conical tubercle, fifth segment longer than third and fourth combined.

Host.—*Larix occidentalis.*
Type locality.—Moscow, Idaho.
Type.—Catalog no. 43839, United States National Museum.

Type, allotype, and 21 paratypes (Hopkins U.S. 225d) taken on Cedar Mountain, near Moscow, Idaho, June 4, 1899, by A. D. Hopkins; 2 paratypes (Hopkins U.S. 8530) collected at Columbia Falls, Mont., by Josef Brunner; 5 paratypes (Hopkins U.S. 16313a) taken at Coeur d'Alene, Idaho, August 8, 1918, by J. C. Evenden.

SCOLYTUS FISKEI, new species

Male.—Shining black, with elytra very dark reddish brown; 2.77 mm long, exclusive of head, about 2.1 times as long as wide.

Front of head sloping, flattened well behind the eyes, not concave; surface shining, rather coarsely aciculate, with rather fine punctures interspersed, from which arise fine, moderately short hairs (less numerous, finer, and shorter than in *laricis*); epistomal process moderately broad and low, moderately deeply and broadly emarginate. Eye elongate, widest above, with inner line very broadly, rather shallowly emarginate. Antenna lighter in color, club 1.41 times as long as funicle, 1.45 times as long as wide, irregularly ovate, widest distally to middle, sutures strongly angulate.

Pronotum wider than long, widest just behind middle; sides arcuate, constricted near anterior margin, broadly subtruncately rounded in front; surface shining, moderately finely and closely punctured (as in *laricis*), coarser on sides and denser in anterior constriction; glabrous except at anterior and lateral borders; marginal line distinct and strongly elevated.

Elytra wider than pronotum, about 1.23 times as long as wide; sides subparallel; broadly, conjointly rounded behind, hind margin scarcely at all serrate, weakly dehiscent at suture; surface shining, disk glabrous, moderately deeply depressed near scutellum; striae variably impressed, punctures moderately fine, deep, variable in spacing but moderately close on first two striae; interspaces sometimes feebly impressed, punctures much finer; caudal sixth rather strongly depressed, punctures confused, coarser and closer and some of them bearing setae.

Venter of abdomen with second sternite nearly vertical, moderately margined anteriorly, surface shining, punctures sparse, moderately fine, deep, median spine longer than in *laricis*, not so stout and strongly, laterally compressed, with base extending from posterior border about three-fourths the length of the segment; remaining sternites moderately shining, short, finely, more closely punctured, fifth but little larger than either third or fourth, concave, with a strong, elevated posterior margin.

Female.—Usual sexual differences, with frons convex and less hairy. Elytra subscabrous at base and feebly serrate on posterior lateral margins. Second sternite more convex, with median spine reduced to a sharp, conical tubercle, and fifth sternite longer than third and fourth combined.

Host.—*Pseudotsuga taxifolia.*
Type locality.—Capitan Mountains, N.Mex.
Type.—Catalog no. 43840, United States National Museum.

Type, allotype, and 5 paratypes (Hopkins U.S. 3959) collected April 25, 1907, at the type locality by W. F. Fiske; 4 paratypes (Hopkins U.S. 9914k) taken at Larkspur, Colo., by W. D. Edmonston; 4 paratypes (Hopkins U.S. 5700a) collected in the Sacramento Mountains, N.Mex., by J. L. Webb; 2 paratypes (Hopkins U.S. 6354) collected at Fort Garland, Colo., by A. D. Hopkins.

This species is closely related to *Scolytus laricis* but is slightly larger, the frons of the male is not concave and is less hairy, the venter of the abdomen is more shining, the spine on the second sternite is longer and less stout, and the last sternite is shorter.

SCOLYTUS UNISPINOSUS Leconte

Male.—Shining black; 2.4 mm long (exclusive of head), about 2.15 times as long as wide.

Front of head sloping, flattened to a point well behind eyes, impressed between eyes; surface shining, very finely aciculate-punctate, with very fine light-colored hairs of medium length; epistomal process moderately wide, low, not strongly emarginate. Eye elongate, wider above, inner line very broadly, feebly emarginate. Antenna testaceous, club 1.44 times as long as funicle, 1.47 times as long as wide, irregularly ovate, widest distally to middle, sutures moderately angulate.

Pronotum wider than long, widest at about middle, posterior outline feebly bisinuate, sides rounded, constricted in front; surface moderately shining, black except at anterior margin; finely, not densely punctured, more densely and coarsely in anterior constriction; glabrous except at borders; margin distinct posteriorly, still more distinct at sides.

Elytra scarcely wider than pronotum, sides subparallel, very broadly rounded (subtruncate) behind; posterior margin not serrate, feebly dehiscent at suture; surface shining, glabrous except at sides and in posterior depression; deeply impressed in scutellar region; striae variably impressed on disk, punctures moderately fine and deep, not close; punctures of interspaces much finer, some of interspaces variably, more weakly impressed; striae with punctures not in regular rows; caudal sixth moderately depressed, the punctures irregularly arranged, dense, some of them bearing setae.

Venter of abdomen with second sternite nearly perpendicular, feebly convex, subopaque, with sparse rather fine punctures, with a stout, obtuse, compressed spine directed caudad, its base extending from posterior margin to middle of segment; third and fourth sternites short, subopaque, finely, moderately closely punctured; fifth sternite shorter than third and fourth together, concave, with a strongly elevated, arcuate posterior margin.

Female.—Similar to male in general characters, but front of head convex, more finely aciculate-punctate, and with shorter hairs. Base of elytra feebly scabrous. Spine on second sternite replaced by an acute conical tubercle.

The foregoing description of the male was prepared entirely from Leconte's type with the exception of the details of antennal structure. In his description Leconte mentions two specimens, both from Oregon, but only one specimen is now in the collection at Cambridge, Mass.

Scolytus unispinosus is a common species in *Pseudotsuga taxifolia*. Specimens have been studied by the writer from California, Oregon, Washington, and British Columbia. Allied species occur throughout the Rocky Mountian region.

SCOLYTUS PICEAE Swaine

Male.—Shining, black, or nearly so; 2.2 to 3.1 mm long, exclusive of head, about 2.1 times as long as wide.

Front of head flattened to well behind eyes, distinctly impressed between eyes; epistomal process short, broad, rather low, rather broadly emarginate; surface coarsely punctate-aciculate, the rather coarse, deep punctures bearing moderately slender yellowish-brown hairs of moderate length. Eyes elongate, with front margin broadly but shallowly emarginate. Antenna yellowish brown, club 1.4 times as long as funicle, 1.66 times as long as wide, the shape irrregularly oval, widest near middle, sutures angulate.

Pronotum 1.12 times as wide as long, widest behind; sides convergently arcuate, strongly constricted near anterior margin, which is lighter in color; surface brightly shining, glabrous except at anterior and lateral margins, moderately coarsely punctured, more coarsely and densely on sides and in front; posterior marginal line sharp and distinct and continued at sides to anterior constriction.

Elytra very slightly wider than pronotum, 1.13 times as wide as long; sides subparallel, feebly arcuate, rounded at posterior angles, subtruncate behind; color dark reddish brown to black; surface shining, glabrous except at sides and in posterior depression, deeply impressed near scutellum; striae variably impressed, more strongly at base and behind, strial punctures moderately coarse, deep; those of interspaces finer; caudal region slightly depressed, punctures here and on sides confused, bearing setae.

Venter of abdomen with rather coarse punctures and slender hairs; second sternite separated from first by a rather weakly elevated margin, with a long, slender, rather blunt spine arising from its center and directed obliquely downward; third and fourth sternites short, opaque; fifth sternite slightly shorter than third and fourth together, concave, with a strongly elevated, arcuate posterior margin.

Female.—Differing from male in that front of head is convex above, transversely impressed on epistoma, more finely punctate-aciculate, and with shorter hairs. Elytra with the base somewhat scabrous and the striae more impressed. Spine on second sternite more slender and often shorter and conical; fifth sternite longer than third and fourth combined.

This species was described by Swaine from specimens collected at Hudson, Quebec, from white spruce. The writer has studied specimens from Maine, New York, Michigan, Wisconsin, South Dakota, North Dakota, Montana, Colorado, Wyoming, and Manitoba. The hosts, where data were given, were *Picea canadensis*, *P. rubens*, *P. engelmannii*, *Larix laricina*, and *Abies balsamea*. In certain sections, as in Maine and in the Western States, the ventral spine in the female is usually but little smaller than in the male, although females having the much reduced spine are sometimes found. In other sections, as in Michigan and Wisconsin, a considerable proportion of the females have the ventral spine much shorter than do the males.

SCOLYTUS MULTISTRIATUS Marsham

Male.—Dark reddish brown in color with the pronotum mostly black; 2.2 to 3.0 mm long, exclusive of head, 2.03 times as long as wide.

Front of head flattened to well behind eyes; epistomal process short and low, broadly, strongly emarginate anteriorly; surface aciculate, with ridges slightly converging and often joining in median line to form a carina, distinctly, deeply punctate, with numerous fine, rather long, incurved yellow hairs except near median line. Eye elongate, with inner line broadly and shallowly emarginate. Antenna yellowish brown, club 1.61 times as long as funicle, 1.58 times as long as wide, slightly irregularly ovate, widest just distad of middle, sutures sharply angulate.

Pronotum slightly wider than long, widest at middle, posterior outline feebly bisinuate, sides arcuate, moderately constricted near anterior margin; surface shining, glabrous on disk; punctures close, moderately fine, denser and coarser on sides and in front; marginal line at back and sides fine but distinct.

Elytra slightly wider than pronotum, about 1.3 times as long as wide; sides feebly arcuate, broadly rounded behind and feebly emarginate at suture; surface shining, glabrous on disk; striae impressed, with rather close, moderately fine punctures; interspaces nearly equally striate and with finer punctures; caudal sixth moderately depressed, punctures confused and bearing setae.

Venter of abdomen finely and densely punctured; second sternite nearly vertical, rather sharply margined anteriorly, with a rather long, subcapitate spine arising from its anterior third; third and fourth sternites short, each usually with a small median tubercle on posterior margin; fifth segment longer than third and fourth combined, concave, with a sharply elevated, arcuate posterior margin.

Female.—Usual frontal differences and ventral spine usually smaller.

This species is a European form which has been accidentally introduced into the Eastern States and breeds in dead or injured elm. It was first observed in Cambridge, Mass., in 1909 and reported by Chapman (*9*) the following year. Specimens taken in Massachusetts, Connecticut, Long Island, N.Y., New Jersey, and Pennsylvania have been studied by the writer, as well as series from Germany, France, and Russia.

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THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS—SECOND REPORT

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INTRODUCTION

In Technical Bulletin 316 of the United States Department of Agriculture (*16*) [1] a report was given on the physical and chemical characteristics of the soils from the erosion experiment stations which had been established up to 1932. The report covered Houston black clay at Temple, Tex.; Kirvin fine sandy loam at Tyler, Tex.; Vernon fine sandy loam at Guthrie, Okla.; Shelby silt loam at Bethany, Mo.; Colby silty clay loam at Hays, Kans.; Cecil sandy clay loam at Statesville, N.C.; Palouse silt loam at Pullman, Wash.; and Marshall silt loam at Clarinda, Iowa. Since that bulletin was completed early in 1932, two new stations have been established, one on Clinton silt loam at La Crosse, Wis., and the other on Muskingum silt loam at Zanesville, Ohio. In addition, a series of plots have been established on Nacogdoches fine sandy loam at the Tyler (Tex.) station. The physical and chemical characteristics of these three soils, together with other data bearing on the erosional characteristics of all of the soils, are presented in this bulletin. Especially important among these are the volume relations of the soils and their settling volumes compared with their other water relations.

When an erosion station is established a 50-pound sample is collected from each important layer of the soil profile down to and includ-

[1] Italic numbers in parentheses refer to Literature Cited, p. 61.

ing the upper part of the parent material. These samples are sent to this laboratory, small subsamples are removed for study, and the remainder is placed in storage. In this and in the previous bulletin (*16*) these samples are designated as typical profile samples or profile samples.

As soon as the plots are established, a composite sample is taken of each soil layer in each plot, the plot being sampled at 10-foot intervals. The soil layers, to a depth of 48 inches, are sampled in this manner. These samples are designated as profile composite samples, or profile composites.

At the end of each year, each plot is sampled to a depth of 7 inches at 10-foot intervals and the samples composited. These samples are designated as annual composites.

In addition, an aliquot of the run-off and the wash-off is taken after each rain and evaporated to dryness. At the end of each year the accumulated samples from each plot are sent to the laboratory for analysis. The size of the aliquot taken depends on the treatment of the plot, the aim being to have an accumulated sample of wash-off at the end of the year of at least 100 grams. In some cases, particularly with the sod plots, the total erosion is very small and does not result in a sample sufficient for analysis.

EXPERIMENTAL METHODS

The same methods of analysis were used in this work as in that previously reported. The mechanical analyses were made by the method of Olmstead and others (*17*). The colloid by water vapor absorption was determined by the method of W. O. Robinson (*19*). The moisture equivalent was determined by the method of Briggs and McLane (*5*). The suspension percentage and dispersion ratios were determined by the method of Middleton (*14*). Percolation ratios were computed by the formula of Slater and Byers (*21*). Colloids were extracted by the method outlined by Holmes and Edgington (*11*). Chemical analyses of the soils and colloids were made by the methods of W. O. Robinson (*20*). The pH determinations were made electrometrically, by means of the hydrogen electrode (*4*). Specific-gravity determinations were made by the method outlined by Hillebrand (*10 pp. 55–57*).

DESCRIPTION OF SAMPLES

The 3 new soils discussed in this bulletin are described in the same manner as the 8 soils in the previous bulletin (*16*). The series description is taken from the files of the Division of Soil Survey of this Bureau, while the specific description of the samples are those given by the collectors.

NACOGDOCHES SERIES

The Nacogdoches soils consist of brown to reddish-brown fine sandy loam, overlying red clay subsoil, which is quite friable, although not so friable as the subsoil of Orangeburg or Greenville. At depths of about 2 to 4 feet, there is considerable bright-yellow extremely friable material of ocherous character. The substratum, or partly decomposed parent material, consists of greenish-yellow soft material derived apparently from a glauconitic limestone. There is much greenish-yellow, soft and semihard rock throughout the profile of

many areas, and there are frequently shell casts derived from the underlying limestone which is of a rather greenish color. The soil is very high in content of iron and low in silica. It is much like the red soils of eastern Cuba, which have undergone very extreme weathering.

The samples of Nacogdoches fine sandy loam were collected in March 1932 by B. H. Hendrickson at the erosion station, 9 miles northwest of Tyler, Tex. They were described by Mr. Hendrickson as follows: (1) From 0 to 8 inches, chocolate brownish-red gravelly fine sandy loam; (2) from 8 to 18 inches, blood-red clay; (3) from 18 to 40 inches, red-yellow clay; (4) from 40 to 66 inches, red-yellow clay, some sand grains; and (5) from 66 to 72 inches, red-yellow sandy clay, rather heavy.

CLINTON SERIES

The Clinton series is characterized by gray or gray-brown soils and by light-brown or yellowish-brown compact subsoils. The subsoils are not highly calcareous. The topography is rolling to broken and drainage is well established. The soils are derived by weathering from loess and are typically developed north of Missouri in the loess belt on the eastern bank of the Mississippi. The series differs from the Memphis in the gray or gray-brown color of the soil and from the Knox in having a more compact subsoil and a lower lime content in both soil and subsoil.

The samples of Clinton silt loam were collected by R. H. Davis in August 1932 at the erosion station, 4 miles east of La Crosse, Wis. In the Soil Survey of La Crosse County, Wis. (*9*) this soil was mapped as Knox silt loam. This designation is still used in Wisconsin and the profile has been described very completely by Kellogg (*12*). The samples were described by Mr. Davis as follows: (1) From 0 to 8 inches, dark-brown heavy silt loam; (2) from 8 to 20 inches, yellowish-brown granular heavy silt loam; (3) from 20 to 32 inches, dark grayish-yellow friable silt loam; (4) from 32 to 44 inches, splotched yellow and gray friable silt loam; and (5) from 44 to 66 inches, sandy clay splotched brick red and gray, soft red sandstone and flint stone present.

MUSKINGUM SERIES

The soils of the Muskingum series consist, in the uncultivated soil, of a dark-brown layer, ranging up to about 4 or 5 inches in thickness. In the types heavier than sand or loamy sand, the structure is coarsely granular. The subsurface, ranging up to a thickness of about 2 inches, is gray or pale yellow, silty or sandy, and where silty, has a well-defined platy structure. The upper subsoil is yellowish brown, often with a more or less well defined reddish shade, decidedly heavier than the gray layer in texture but not sufficiently heavy to constitute a hardpan or claypan. The upper part of this layer breaks into small angular fragments due to jointing, the fragments ranging around one-fourth to one-half inch in diameter, but downward these fragments become larger and the jointing less well defined. The lower part of this layer grades into somewhat loose disintegrated sandstones and shales, or lies on partly decomposed shale or sandstone. The thickness of this layer ranges up to about 2 feet. This soil series occurs in southeastern Ohio, in western Pennsylvania, West Virginia,

and probably elsewhere, and is included among the soils of the mid-latitude zone of the United States east of the prairies. It was formerly included in the Dekalb soils.

The samples of Muskingum silt loam were collected by E. B. Deeter in April 1933, at the erosion station, 7 miles west of Zanesville, Ohio. They are described by Mr. Deeter as follows: (1) (*a*) From 0 to 1 inch, light grayish-brown silt loam (when dry), mixed with grass roots and organic matter. When wet, the color is a fairly dark brown. This was mixed to form one sample with (*b*) from 2 to 7 inches, yellowish-brown silt loam, with small pieces of shale in small to almost negligible quantity. Very compact and puddles easily. In fields, the dry soil is inclined to crust, and in this condition water tends to run off rather than to percolate into the soil. (2) From 8 to 13 inches, yellow silty clay loam with very faint mottling of gray or light yellow. Contains small pieces of black material (manganese?). Compact and difficult to penetrate. (3) From 14 to 24 inches, compact yellow silty clay, mottled somewhat with gray. Fragments of shale are present. (4) From 25 to 46 inches, light reddish-yellow silty clay, with faint mottlings of gray. Very compact, and shale is abundant. (5) From 47 to 72 inches, heavy dense gray clay with some mottlings of yellow. Shale is present but not abundant.

COMPOSITION AND PROPERTIES OF THE PROFILE SAMPLES

PHYSICAL PROPERTIES

The various physical tests and their relationship to erosional behavior were very fully discussed in the previous bulletin (*16, pp. 13–15*). The general discussion will not be repeated here. However, each of the three new soil profiles will be considered not only with respect to their relationship to each other but also to the eight profiles previously studied. The physical data and hydrogen-ion concentration are presented in table 1.

TABLE 1.—*Mechanical analyses* [1] *and physical data of typical profiles of erosion-station soils*

Sample no.	Depth	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Organic matter by H_2O_2	Colloid <0.002 mm	Colloid by water-vapor absorption	Moisture equivalent	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Suspension percentage	Percolation ratio	pH
	Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*						
NACOGDOCHES FINE SANDY LOAM, TYLER, TEX.																		
9475	0–8	[2] 2.0	0.9	10.3	48.4	8.1	9.8	18.0	2.2	16.1	18.6	14.3	28.2	1.30	21.7	7.84	6.0	5.3
9476	8–18	.2	.5	7.4	32.3	5.3	4.9	48.4	.7	47.1	50.5	25.2	13.8	2.00	6.9	7.38	-------	4.4
9477	18–40	.2	1.1	10.5	37.5	5.8	5.9	38.9	.0	38.2	52.5	25.1	16.0	2.09	7.7	7.17	-------	4.6
9478	40–66	.1	.3	11.2	47.0	6.2	.8	34.3	.0	31.7	32.9	18.6	11.5	1.77	6.5	4.04	-------	5.0
9479	66–72	.2	1.1	11.6	41.4	6.0	5.6	34.0	.0	32.7	45.2	22.5	12.4	2.01	6.2	4.93	-------	5.1
CLINTON SILT LOAM, LA CROSSE, WIS.																		
10362	0–8	0.0	0.2	0.3	0.6	4.9	72.7	19.1	1.7	11.2	13.7	23.9	32.9	0.57	57.7	30.22	53.0	5.9
10363	8–20	.0	.1	.1	.3	6.1	68.5	24.3	.1	18.8	20.3	23.5	26.7	.86	31.0	24.75	-------	5.3
10364	20–32	.0	.1	.2	.4	6.3	65.8	27.0	.0	21.8	24.7	24.7	35.5	1.00	35.5	32.90	-------	5.2
10365	32–44	.0	.7	1.6	1.7	6.7	66.5	22.4	.0	18.2	21.1	22.4	39.2	.94	41.7	34.82	-------	5.4
10366	44–66	1.0	13.7	31.0	19.0	3.9	7.6	23.2	.0	21.4	19.8	13.8	34.8	1.43	24.3	10.71	-------	5.6
MUSKINGUM SILT LOAM, ZANESVILLE, OHIO																		
B407	0–7	0.6	1.3	1.0	1.3	2.1	63.2	28.4	1.9	19.9	21.0	25.5	34.5	0.82	42.1	31.60	38.5	4.7
B408	8–13	1.7	2.1	1.2	1.6	2.6	53.2	37.1	.3	27.3	30.4	26.2	23.1	1.16	19.9	20.90	-------	4.8
B409	14–24	4.2	4.6	2.7	4.2	5.5	43.9	34.8	.0	25.3	27.6	21.0	30.3	1.31	23.1	23.86	-------	4.8
B410	25–46	4.2	3.6	2.7	4.2	10.2	46.5	28.3	.0	20.3	19.0	19.4	41.1	.98	41.9	30.77	-------	4.8
B411	47–72	1.1	1.6	2.0	7.0	6.1	51.6	30.4	.0	19.0	17.3	19.8	51.9	.87	59.6	42.55	-------	6.4

[1] Determinations by H. W. Lakin, T. M. Shaw, and F. P. Trilety

[2] 50.8 percent of this sample consisted of gravel > 2 mm.

In the previous bulletin (*16*), the soils were divided into two groups on the basis of their mechanical analyses—those in which the texture is variable within the profile, and those with uniform texture throughout. However, in the latter group, the uniformity is relative rather than absolute. On the same basis the Nacogdoches would be placed in the first group with the Kirvin, Vernon, and Cecil, while the Clinton and Muskingum would be placed in the second group with the Houston, Colby, Palouse, Marshall, and Shelby.

The Nacogdoches profile consists of a sandy topsoil over a heavy clay subsoil, but the difference is not as great as in the Kirvin profile which occurs at the same station. The mechanical analyses of this profile indicate considerable weathering, which is confirmed by the chemical analyses, which will be discussed later. The surface horizon contains over 50 percent of gravel and rock which do not pass the 2-millimeter sieve, and hence do not enter into the analysis. This gravel undoubtedly has an important bearing on the physical and erosional properties of the soil in the field, but cannot be considered from the laboratory viewpoint. The three lower horizons of the profile are remarkably uniform in texture, as well as in the other physical properties. The fourth horizon is notable in that it contains practically no silt. The texture of the whole profile is unusual in that the bulk of the material falls into the fine sand and clay groups, with very little very fine sand and silt.

Clinton and Muskingum silt loams are similar in texture to the other silt loams, particularly the Palouse and Marshall. Both have slightly less clay and more silt in the first horizon than in the second, but the sum of the silt and clay is very nearly the same in both. The third horizon of the Clinton contains more clay and colloid and less silt than the second, which indicates that conditions are more favorable for illuviation in this horizon than in the second. This is not usual in soils. The fifth horizon contains about the same percentage of clay as the layers above but the remainder of the material is altogether different and evidently constitutes the original material upon which the loess was deposited.

The three lower horizons of the Muskingum are quite uniform in texture. There is a gradual decrease in colloid content from the second to the fifth horizon, in which it is practically the same as in the first horizon.

Certain physical characteristics of soils have been shown by Middleton (*14*) to be indicative of erosional behavior. These properties are the dispersion ratio, the ratio of colloid (by water-vapor absorption) to moisture equivalent, and the erosion ratio. The suspension percentage which is used in both the determination of the dispersion ratio and the percolation ratio is the fraction consisting of silt and clay, expressed in percentage of the soil, which is dispersed, and remains suspended in distilled water under specific conditions (*14*). The dispersion ratio is the ratio of the suspension percentage to the total percentage of silt and clay in the soil, multiplied by 100. The erosion ratio is the quotient obtained by dividing the dispersion ratio by the ratio of colloid to moisture equivalent. The percolation ratio is the quotient obtained by dividing the suspension percentage by the ratio of colloid to moisture equivalent. A full explanation and discussion of these determinations is given in the previous report (*16*).

The physical properties other than the mechanical analyses indicate the Nacogdoches to be the least erosive of the three soils. The dispersion ratio is low and the colloid-moisture equivalent ratio is high, resulting in a low value of the erosion ratio. This applies particularly to the surface horizon which is a fine sandy loam. It is exceptional for a soil of this class to have a low dispersion ratio. This is unquestionably owing to the chemical character of the colloid, which makes it highly resistant to dispersion by water. Kirvin fine sandy loam (*16*) which occurs at the same station has a much higher dispersion and erosion ratio and lower colloid-moisture equivalent ratio in the surface horizon. The suspension percentage and percolation ratio are also low, the percolation ratio being the lowest of any of the 11 erosion station soils. In the second and lower horizons the colloid-moisture equivalent ratios are exceptionally high, in the experience of the writers having been exceeded only by the Nipe clay from Cuba reported by Middleton (*14*). This, together with the low value of the dispersion ratio, results in low values of the erosion ratios comparable with those of the lower horizons of the Kirvin and Cecil. The erosion ratios of the four lower horizons are all of nearly the same value, indicating that the layers are about equally resistant to erosion. A general summary of the physical properties of this soil indicates that it should be the most resistant to erosion of any of the 11 soils, and that such erosion as occurs should be of the sheet rather than the gully type. This accords with field experience.

The physical properties of the Clinton soil, on the other hand, indicate that it should be the most erosive of the 11 soils. In all horizons the erosion ratio is high and is the highest of all the erosion station soils in the surface horizon. The dispersion ratios and suspension percentages are all very high and the colloid-moisture equivalent ratios are low. The percolation ratio is the highest of all of the soils, as is also the silt content, both of which have been shown by Slater and Byers (*21*) to have an important bearing on permeability. These data indicate that percolation in this soil should be very slow, consequently the run-off should be large, which, taken together with a very erosive soil, should result in very rapid erosion.

The data for the Muskingum soil indicate that it is not quite as susceptible to erosion as the Clinton. The second horizon has a lower erosion ratio than in the Clinton, but in the lower horizons the erosion ratio increases with depth and the fifth horizon has a higher erosion ratio than the first, which condition generally favors severe gully formation. As compared to the silt loam soils previously reported, the data indicate that the Clinton and Muskingum should be much more susceptible to erosion than the Marshall, Palouse, or Shelby. It has been the writers' observation that silt loam soils are particularly susceptible to erosion owing to the fact that the large quantity of silt and comparatively small quantity of colloid are not conducive to the formation of a firm aggregated structure which is necessary to resist the erosive effects of surface wash. The same thing is true of the sandy soils, particularly the fine sandy loams, which have about the same quantity of colloid but with the silt replaced by fine sand and very fine sand. This condition is favorable for a very friable, loose structure which is desirable for tillage operations but also is conducive to severe erosion except on level surfaces. The

character of the colloid is undoubtedly of greater importance than the amount, as is shown by the Nacogdoches. Compared with the surface horizons of the Clinton and the Muskingum, the surface horizon of the Nacogdoches is intermediate in quantity of colloid but the character of the colloid is such that it places the Nacogdoches far below the Clinton and Muskingum in susceptibility to erosion.

CHEMICAL COMPOSITION OF THE SOIL AND COLLOID OF REPRESENTATIVE PROFILES

In table 2 are presented the complete analyses of three of the representative profiles of the erosion-station soils. The corresponding data for the other eight soils in the erosion-station series are to be found in Technical Bulletin 316, table 2 (*16*). The analyses of the whole soil do not furnish the detailed information concerning the soil character which may be obtained by colloid analyses, but they are essential to the presentation of a complete picture of the soils. In addition, they offer certain specific information not furnished by either the mechanical or colloid analyses.

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TABLE 2.—*Chemical analyses of typical profiles of erosion-station soils*

Sample no.	Depth	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	Ignition loss	Total	N	Organic[1] matter	Ratio of organic matter to nitrogen
	Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
NACOGDOCHES FINE SANDY LOAM, TYLER, TEX.																	
9475	0– 8	76.00	0.48	11.80	5.93	0.07	0.51	0.12	0.19	0.02	0.26	0.16	4.99	100.53	0.10	1.89	18.9
9476	8–18	60.45	.51	15.72	14.75	.01	.37	.21	.26	04	.27	.10	6.90	99.59	.06	1.13	18.8
9477	18–40	61.60	.47	17.78	12.56	.00	.29	.21	.18	.00	.29	.14	6.25	99.77	.03	.42	14.0
9478	40–66	76.85	.53	5.82	11.82	.00	.22	.03	.22	.01	.20	.02	4.40	100.12	.02	.11	5.5
9479	66–72	65.50	.46	16.93	11.19	.00	.12	.04	.16	.01	.34	.03	5.29	100.07	.02	.19	9.5
CLINTON SILT LOAM, LA CROSSE, WIS.																	
10362	0– 8	76.80	0.33	1.92	11.46	0.15	0.33	0.16	2.30	1.12	0.22	0.22	4.13	99.14	0.13	1.55	11.9
10363	8–20	75.50	.71	3.87	11.76	.08	1.22	.41	2.32	1.05	.22	.14	3.21	100.49	.05	.59	11.8
10364	20–32	73.40	.72	4.10	12.87	.07	1.06	.35	2.23	1.09	.16	.11	3.14	99.30	.04	.36	9.0
10365	32–44	75.10	.72	3.70	11.85	.07	.94	.26	2.58	.89	.19	.03	2.69	99.02	.03	.28	9.3
10366	44–66	82.30	.76	2.78	10.14	.00	1.09	.19	.49	.32	.16	.04	2.50	100.77	.02	.18	9.0
MUSKINGUM SILT LOAM, ZANESVILLE, OHIO																	
B–407	0– 7	75.18	1.12	3.74	11.11	0.12	0.49	0.05	2.11	0.72	0.06	0.07	5.20	99.98	0.15	2.41	16.1
B–408	7–13	68.49	.88	6.48	15.42	.09	.42	.20	2.49	.61	.03	.05	4.71	99.87	.06	.53	8.8
B–409	14–24	59.21	1.01	8.00	21.37	.07	.26	.30	2.93	.38	.04	.02	6.45	100.04	.04	.20	5.0
B–410	25–46	60.91	1.10	6.54	21.50	.07	.22	.05	2.79	.18	.01	.03	6.14	99.54	.04	.13	3.2
B–411	47–72	59.47	1.11	7.17	21.86	.11	.28	.09	3.28	.18	.03	.02	6.15	99.75	.04	.11	2.8

[1] CO_2×factor 0.471.

None of the three soils under discussion, the Nacogdoches fine sandy loam, the Clinton silt loam and the Muskingum silt loam, is calcareous, and consequently no determination was made of the trace amounts of carbonates which normally occur (*1*). The Nacogdoches is a red soil which is highly weathered and with low base and very high iron oxide content. The relations in general are those of a soil practically free from undecomposed minerals other than quartz. The organic matter in all three soils shows the usual concentration in the A horizon and the normal decrease in the carbon-nitrogen ratio except in the case of the lowest stratum of the Nacogdoches (*2*). The small increase of organic matter without corresponding increase of nitrogen is not adventitious. In this layer B. H. Hendrickson, of the Tyler Station, has reported the presence of graphite particles. The lowest stratum of the Clinton silt loam shows in its analytical results the same divergence from the material above it as is indicated by the mechanical analyses (table 1). This divergence is not so marked in the colloidal material (table 3).

All three soils show evidence of the operation of the podzolization process in respect to concentration of iron oxide and alumina in the B horizons. The Clinton and Muskingum soils show the presence of considerable quantities of undecomposed feldspars. The pH values (table 1) of all three soils are low and indicate a high degree of leaching. It is to be remarked that the acidity of the Muskingum soil is materially greater in the A horizon than the Nacogdoches, despite the greater quantity of bases.

The analyses of the colloids of the three soil profiles are given in table 3. These colloids were extracted in the usual manner by use of a supercentrifuge. No attempt was made at complete extraction of the colloid, but only to make the extraction sufficiently exhaustive so that the material should be fully representative of the total colloid. For this purpose the soil was dispersed from 4 to 8 times until the quantity of colloid obtained showed marked decrease. The centrifuge was run at such a rate that no particles larger than 1μ were obtained in the colloid material (*6*). No dispersing agent, other than water was used except in the lower three layers of the Nacogdoches, in which it proved desirable to add a small quantity of ammonia to increase the stability of the dispersion. The quantity of colloid extracted, as compared with the total quantity present, varied from 45 percent in the case of the Nacogdoches surface soil to 98 percent in the case of the fourth layer of the Muskingum. This latter is an unusually large fraction of the total colloid. The colloids were collected from the centrifugate by filtration through Pasteur-Chamberland filters, and were dried on a water bath. The analyses, as reported, are comparable in all respects with those given in Technical Bulletin 316 (*16*) for the other erosion-station soils, except that the organic matter is determined by combustion and the trace quantities of carbonates were not determined.

TABLE 3.—*Chemical analyses of colloids in typical profiles of erosion-station soils*

NACOGDOCHES FINE SANDY LOAM, TYLER, TEX.

Sample no.	Depth	Colloid extracted	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	Ignition loss	Total	N	Organic matter [1]	Ratio of organic matter to nitrogen
	Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
9475	0–8	45	27.00	0.59	30.60	23.20	0.19	1.28	0.20	0.53	0.10	0.76	0.13	15.54	100.12	0.34	3.32	9.8
9476	8–18	87	31.35	.61	26.71	26.97	.03	.59	.21	.24	.04	.36	.06	12.22	99.39	.15	1.26	8.4
9477	18–40	71	30.81	.59	25.95	28.50	.02	.52	.12	.34	.08	.46	.09	12.21	99.69	.14	.74	5.3
9478	40–66	70	38.12	.67	16.66	31.06	.02	.46	.20	.64	.10	.36	.05	12.20	100.54	.16	.38	2.4
9479	66–72	58	29.80	.58	29.57	25.08	.03	.33	.28	.17	.09	.55	.05	12.62	99.15	.17	.57	3.4
CLINTON SILT LOAM, LA CROSSE, WIS.																		
10362	0–8	75	45.10	0.76	7.02	23.99	0.43	1.36	1.88	1.83	0.16	0.68	0.16	17.07	100.44	0.55	4.89	8.9
10363	8–20	84	47.10	.76	10.00	25.27	.21	1.07	2.04	1.59	.09	.60	.16	11.48	100.37	.18	1.60	8.9
10364	20–32	80	47.85	.69	11.65	23.61	.15	1.16	2.01	1.59	.12	.60	.12	10.37	99.92	.13	1.25	9.6
10365	32–44	79	48.30	.74	8.02	27.05	.14	.97	2.12	1.52	.14	.54	.12	10.38	100.04	.18	1.37	7.6
10366	44–66	88	48.45	.77	6.49	30.20	.03	.77	1.32	1.22	.08	.39	.07	10.94	100.73	.08	.59	7.4
MUSKINGUM SILT LOAM, ZANESVILLE, OHIO																		
B-407	0–7	55	44.00	0.62	9.97	26.67	0.14	0.93	1.98	2.51	0.17	0.49	0.09	13.18	100.75	0.36	3.94	10.9
B-408	7–13	77	43.10	.72	13.00	27.26	.11	.95	1.90	2.78	.06	.44	.05	10.00	100.37	.19	1.25	6.6
B-409	14–24	93	42.70	.73	11.13	29.79	.06	.65	1.54	3.25	.12	.55	.02	9.55	100.09	.11	.52	4.7
B-410	25–46	98	45.05	.84	8.28	30.73	.05	.74	1.21	3.56	.09	.60	.01	9.08	100.24	.11	.30	2.7
B-411	47–72	78	46.80	.92	5.26	31.30	.07	.82	1.62	4.26	.16	.80	.02	8.39	100.42	.11	.27	2.5

[1] CO_2 × factor 0.471.

Comparison of the data of table 3, for the colloids, with those of table 2, for the soils, shows the same general relationships as in the other erosion-station soils. The silica content of the colloids is much less than that of the soils and the sesquioxide content correspondingly greater. The calcium content of the colloids is greater in general than in the soils, and particularly is this the case in the surface horizons. Magnesium also concentrates in the colloid of the Clinton and Muskingum soils, as is generally true of the erosion-station soils, but this is not the case with the three samples from upper layers of the Nacogdoches, and in this respect it stands alone. The nearest approach to this behavior is in the Kirvin fine sandy loam at the same station (*16*). Potassium likewise ordinarily concentrates in the colloid but in the Clinton soil this is not the case except in the lowest stratum. Presumably this is additional evidence of undecomposed feldspars in the loess. In confirmation of this the silt was examined by use of a petrographic microscope and found to contain upwards of 5 percent of feldspars. This is quite in harmony with the loessial soils reported by Brown and Byers (*6*). The presence of undecomposed feldspars in the Clinton is also indicated by the high calcium content of the lower portions of the soil, as compared with that in the colloid. The feldspathic content of the Clinton is further indicated by the high sodium content of the soil. The lower sodium content of the extracted colloid is quite in harmony with the usual relation found in humid soils.

The organic matter is uniformly higher in the colloid than in the soil, but by no means all of the organic matter is dispersed. This is shown by comparing the total organic matter with that found in the colloids. In the surface layers only about 30 percent of the organic matter in the soil appears in the colloid. In the lower layers the extracted organic matter rises to nearly 100 percent of that in the soil. In harmony with this relation is the fact that the organic matter-nitrogen relation is uniformly lower in the colloid than in the soil. It is to be expected that undecomposed organic matter which has a high carbon-nitrogen ratio would have less tendency to disperse than well-decomposed material or bacterial remains.

In order to facilitate the comparison of these three soil colloids with each other the derived data are collected in table 4 which is followed by the corresponding data from the eight other erosion-station colloids (table 5). The latter are partly recalculated from table 3 of Technical Bulletin 316 (*16, p. 28*).

TABLE 4.—*Derived data from the colloid analyses of the erosion-station soils.*

NACOGDOCHES FINE SANDY LOAM, TYLER, TEX.

Sample no.	Depth	Mol ratio					Combined water	Total water of soil acid	Mol ratio $\frac{SiO_2}{H_2O}$
		$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$			
	Inches						*Percent*	*Percent*	
9475	0- 8	1.07	1.98	2.35	0.843	12.9	12.22	13.29	0.63
9476	8-18	1.21	1.97	3.12	.632	27.8	10.96	11.44	.83
9477	18-40	1.16	1.83	3.15	.582	29.8	11.47	11.85	.79
9478	40-66	1.53	2.05	6.08	.337	29.4	11.82	12.25	.74
9479	66-72	1.12	1.94	2.68	.723	31.0	12.05	12.40	.72

TABLE 4.—*Derived data from the colloid analyses of the erosion-station soils*—Con.

CLINTON SILT LOAM, LA CROSSE, WIS.

Sample no.	Depth	Mol ratio					Combined water	Total water of soil acid	Mol ratio $\frac{SiO_2}{H_2O}$
		$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$			
	Inches						*Percent*	*Percent*	
10362	0– 8	2.69	3.19	17.19	0.187	8.1	12.18	14.57	0.98
10363	8–20	2.53	3.17	12.52	.253	8.9	9.88	11.64	1.23
10364	20–32	2.62	3.44	10.92	.315	8.9	9.12	10.88	1.34
10365	32–44	2.55	3.03	16.00	.189	9.1	9.01	10.73	1.37
10366	44–66	2.44	2.72	19.85	.137	13.3	10.35	11.52	1.27
MUSKINGUM SILT LOAM, ZANESVILLE, OHIO									
B–407	0– 7	2.26	2.80	11.73	0.239	7.8	9.24	11.34	1.21
B–408	7–13	2.06	2.68	8.81	.305	7.6	8.75	10.53	1.24
B–409	14–24	1.97	2.43	10.2	.239	8.3	9.03	10.06	1.21
B–410	25–46	2.12	2.49	14.5	.172	9.1	8.78	10.23	1.32
B–411	47–72	2.29	2.54	23.6	.107	7.6	8.12	9.95	1.41

The data of the Nacogdoches fine sandy loam offer several points of special interest. In its A horizon it presents the lowest silica-sesquioxide ratio of any soil in the United States, so far reported. This ratio continues to be very low throughout the profile except in the C_1 horizon (40–66 inches). Attention has already been called to the slightly abnormal organic matter content of the C_2 horizon (66–72 inches). The divergence of the C_1 horizon (40–66 inches) from those above it is even more marked. In the mechanical analysis (table 1) it will be noted that there is a sharp increase in the fine sand and an even more marked decrease in the silt content. This is reflected not only in a decidedly different appearance of the soil but in its complete analysis (table 2), which is characterized by a higher silica and lower iron oxide content than the horizons above and below it. This divergence follows into the colloid and shows itself in the silica-sesquioxide, silica-ferric oxide and ferric oxide-alumina ratios particularly but not so markedly, relatively speaking, in the silica-alumina ratio. It would seem clear that this portion of the colloid is derived chiefly at least from a layer of parent material of low iron content.

The Nacogdoches soil is an extremely red soil and the inference may properly be drawn that nearly, if not quite, all of the iron content is free iron oxide. The alumina, on the other hand, is probably associated with the silica. The lateritic character of the colloid is further indicated by its low base content, as shown by the silica-total base ratio. The silica-base ratio of the A horizon is much smaller; in other words, the relative base content is much higher than in lower layers. This may be taken to indicate the greater base-holding capacity of the organic colloid and that a considerable portion of the bases present are associated with the organic matter. The soil of the other erosion stations most similar to the Nacogdoches is the Cecil from North Carolina (table 5). Particular attention is directed to the differences between the Nacogdoches and the Kirvin colloid, which has been developed under identical conditions of temperature and rainfall (table 5).

TABLE 5.—*Derived data from the colloid analyses of the erosion-station soils published in Technical Bulletin 316*

Sample no.	Depth	Mol ratio					Combined water	Total water of soil acid	Mol ratio $\frac{SiO_2}{H_2O}$
		$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$			
	Inches						*Percent*	*Percent*	
CECIL SANDY CLAY LOAM, STATESVILLE, N.C.									
6977	0–6	1.34	1.65	6.94	0.238	13.1	14.65	15.75	0.64
6978	6–32	1.28	1.69	7.27	.233	17.5	13.98	14.58	.69
6979	32–60	1.43	1.88	7.35	.256	25.7	12.85	13.32	.81
KIRVIN FINE SANDY LOAM, TYLER, TEX.									
6678	0–12	2.02	2.75	7.58	0.363	17.5	10.76	11.76	1.10
6679	12–24	1.74	2.28	7.39	.308	17.7	11.32	12.10	1.00
6680	24–51	1.89	2.42	8.81	.274	18.6	11.22	11.92	1.06
6681	51–63	2.03	2.48	10.61	.234	20.3	10.65	11.33	1.17
6682	63–75	1.80	2.47	6.84	.360	24.0	11.03	11.57	1.07
VERNON FINE SANDY LOAM, GUTHRIE, OKLA.									
6718	0–3	2.65	3.45	11.40	0.303	7.0	9.50	12.37	1.12
6719	3–10	2.44	3.12	11.20	.279	7.4	9.43	11.48	1.18
6720	10–27	2.34	2.94	11.38	.259	7.5	9.67	11.58	1.18
6721	27–58	2.35	2.88	13.07	.221	6.7	8.41	10.55	1.21
PALOUSE SILT LOAM, PULLMAN, WASH.									
8069	0–20	2.48	3.23	10.92	0.301	6.6	9.55	12.03	1.16
8070	20–33	2.45	3.31	9.52	.350	7.1	9.56	11.69	1.19
8071	33–62	2.45	3.25	10.02	.324	7.2	9.86	11.90	1.17
8072	62–75	2.57	3.45	10.15	.339	7.4	9.41	11.40	1.26
8073	75–84	2.61	3.50	10.21	.343	7.0	9.30	11.42	1.27
SHELBY SILT LOAM, BETHANY, MO.									
6797	0–8	2.65	3.31	13.22	0.252	8.8	10.38	12.66	1.16
6798	8–12	2.62	3.30	11.42	.262	9.1	10.63	12.52	1.17
6799	12–20	2.60	3.28	11.18	.265	8.7	9.44	11.35	1.30
6800	20–24	2.60	3.36	11.47	.293	7.8	9.41	11.42	1.28
6801	24–48	2.71	3.57	11.22	.319	7.3	8.94	11.03	1.33
6802	48–60	2.67	3.54	10.84	.326	7.4	8.78	10.88	1.35
6802B	60–84	2.91	4.33	8.89	.487	7.6	8.15	10.26	1.47
MARSHALL SILT LOAM, CLARINDA, IOWA									
8736	0–13	2.91	3.69	13.68	0.270	7.6	9.56	12.21	1.23
8737	13–24	2.88	3.66	13.45	.272	7.7	9.87	12.32	1.22
8738	24–45	2.91	3.72	13.40	.278	8.2	9.49	11.56	1.32
8739	45–71	2.83	3.57	13.65	.262	8.7	8.61	10.58	1.43
HOUSTON BLACK CLAY, TEMPLE, TEX.									
6096	0–3	3.26	3.90	19.56	0.200	5.5	9.32	13.77	1.12
6097	14–20	3.24	3.92	18.75	.209	4.8	8.50	13.40	1.13
6098	24–36	3.25	3.91	18.88	.207	5.4	8.13	12.77	1.21
6099	36–50	3.25	3.97	18.45	.215	5.1	8.29	13.08	1.20
COLBY SILTY CLAY LOAM, HAYS, KANS.									
6842	2–10	3.45	4.25	19.41	0.230	6.2	7.49	10.75	1.50
6843	10–20	3.41	4.18	18.47	.227	6.0	7.50	11.17	1.43
6844	20–33	3.47	4.29	18.55	.231	5.7	7.56	11.20	1.44
6845	33–47	3.52	4.27	20.32	.210	5.1	6.94	10.89	1.47
6846	47–60	3.57	4.38	19.39	.226	5.8	7.11	10.66	1.53
6847	60–72	3.56	4.37	19.17	.228	5.2	6.93	10.94	1.47

The Clinton silt loam and the Muskingum silt loam are both representative of the gray-brown podzolic soils but they show marked differences. It is probable that these differences are due in part to the difference in parent material. In the Clinton this is loess, and in the Muskingum is glacial drift. In part, the differences are due to the maturity of the Clinton as compared with the relatively immature Muskingum. It is possible, also, that the Clinton soils have not been wholly developed under forest cover. Their silica-sesquioxide and alumina ratios indicate an acid complex sharply different from the Nacogdoches. The iron content is not free iron oxide, since on treatment with hydrogen peroxide the inorganic residue is nearly white. Nevertheless, both the Clinton and Muskingum soils show distinct evidence of podzolization in the concentration of iron oxide in the B_1 and B_2 horizons. Despite their low pH values (table 1), both colloids have a very high total base content, as compared with Nacogdoches (table 4) and the Cecil and Kirvin (table 5). The other erosion-station soil most closely associated with the Clinton and Muskingum with respect to the colloid properties is Vernon fine sandy loam (table 5). In color, however, the Vernon is markedly different.

In tables 4 and 5, columns 8, 9, and 10, are assembled certain data which require detailed consideration. These involve the water content of the 11 erosion-station soil colloids. "Combined water" of the colloid is determined by subtracting the organic matter and carbon dioxide found from the ignition loss. These values are found in column 8 of the tables. This value is subject to two sources of error, both of which are at present unavoidable. The so-called "organic matter" is determined by combustion and the carbon dioxide found is multiplied by the Wolff factor 0.471. This factor is known to be uncertain (*1*). The ignition loss is determined on the colloid dried at 105° C. It is certain that this temperature produces changes in the organic matter (*1*) and it is illogical to conclude that no combined water is given off at 105°. Despite these uncertainties, the combined water of this series of colloids offers some interesting features. The two lateritic colloids, Cecil and Nacogdoches, show an average percentage of combined water of 13.83 and 11.70 percent, while the next most lateritic colloid, the Kirvin, has a mean value of 10.99. By contrast with these, the three gray-brown podzolic soils, the Vernon, Clinton, and Muskingum, have values of 9.25, 10.11, and 8.78 percent. The three prairie soils, the Marshall, Shelby, and Palouse, have values of 9.38, 9.39, and 9.54 percent. The chernozem soil, the Colby, has a mean value of 7.25 percent. The Houston is not a true chernozem. It is more properly a rendzina soil and has a mean combined water content of 8.56 percent. It is apparent, that, while sharp distinctions are not shown, yet in general it is true that the different great soil groups have distinctively different combined-water values.

In column 9 of tables 4 and 5 are given a series of figures for what is called the "total water of the soil acids." These values are calculated on the assumption that the colloids contain a definite acid, or series of acids, as outlined by Brown and Byers (*6*) and Byers (*7*). If these acids exist the bases present in the colloids may be assumed to replace the water which would otherwise be present, though it must be recognized that a portion of the bases are held by the organic acids. For this purpose, then, the water equivalent of the bases is calculated and the amount is added to the water percentage. Due allowance

is to be made for the carbonates present, which are calculated on the assumption that they are wholly calcium carbonate, and for the organic matter. The resulting values, therefore, represent the water present, on the basis of the inorganic material less the calcium carbonate, as 100 percent. It will be noted that in general this recalculation brings about a decrease in the differences between the water content of the colloids, since the colloids of lower water of combination are those of higher base content. The means of the percentages of the representatives of the four groups become: Cecil, Nacogdoches, and Kirvin, 14.55, 12.25, and 11.74 percent, respectively. The corresponding values for the gray-brown podzolic group become: Vernon, 11.49 percent; Clinton, 11.87 percent; and Muskingum, 10.42 percent. For the prairie group: Marshall, 11.67 percent; Shelby, 11.45 percent; and Palouse, 11.69 percent. For the Houston, the mean percentage is 13.25 percent, and for the Colby 10.93 percent.

In column 10 of tables 4 and 5 are found the molecular ratio of the silica to the total water of the soil acids. In the calculation of these data the ratio has been determined on the total combined water before correcting for the organic matter and carbonates present. This is essential because these affect the silica percentages, as well as the combined water and total bases. These values are of very special significance, since, despite the known sources of uncertainty in the water values, and the possible presence of undecomposed silicate particles of colloidal dimensions, two definite regularities may be observed. The silica-water ratio increases progressively with the silica-sesquioxide ratios. This means that the water content of the colloid increases with increase in the sesquioxide content. If, therefore, decrease of the silica-sesquioxide ratio is regarded as a measure of the degree of weathering, the silica-acid water ratio is a corroborative indication. In each soil profile the general relation is a progressive general increase with depth, as is to be expected if a decrease of the ratio is an indication of increase of water content with increased weathering.

In the paper previously referred to (*7*) in connection with the constitution of the soil acids, it is assumed that an acid of the halloysitic type should, if pure and stable at 105° C., have a combined-water content of 19.6 percent, corresponding to the composition H_3AlSiO_5 ($3H_2O.Al_2O_3.2SiO_2$). In this type of colloid the silica-acid water ratio should be $2SiO_2/3H_2O=0.667$, and the silica-alumina ratio should be 2. The mean value of the SiO_2/H_2O ratio for the Cecil colloid is 0.71 and the silica-alumina ratio is 1.74. In the Nacogdoches colloid the corresponding ratios are 0.74 and 1.95. If, then, as the above statement implies, the iron content of these two soils is assumed to be ferric oxide, anhydrous at 105°, the water content of the soil acid may be recalculated. This is done by multiplying the values shown in column 9 by $\frac{100}{100 \text{ percent} - Fe_2O_3}$. Such assumption and recalculation is not permissible with the other colloids, since their general behavior indicates that the iron present is at least partially associated with the silica. The quantities so arrived at are for the Cecil colloid 18.0, 16.61, and 15.89 percent, respectively, for the three depths, an average of 16.83; and for the Nacogdoches colloid 19.15, 15.61, 16.00, 14.70, and 17.60 percent, respectively, an average of 16.61 percent. When the close relationship to silicic acid that halloysitic

is supposed to have is considered, the results are as nearly theoretical as can reasonably be expected.

A colloid which contains as its major acid component pyrophyllic acid: $H_3AlSi_2O_7(3H_2O.Al_2O_3.4SiO_2)$ should have as its silica-acid water ratio $4SiO_2/3H_2O=1.33$, and a silica-alumina ratio of 4. Its acid-water percentage should be 13.6 percent. The nearest approach to these values among the erosion station soils is found in the Colby colloid. The silica-sesquioxide ratio has a mean value of 3.49. The silica-acid water ratio has a mean value of 1.47. The water content is but 10.93 instead of 13.6 percent. With these facts considered in the light of the properties to be expected of an acid of the type of pyrophyllic acid, the evidence of its existence may be considered as fairly satisfactory. More definite information in this direction must await the development of more accurate determination of the water relations of the colloids, and especially of the combined water evolved before drying at 105° C. is complete.

The other colloids of the erosion-station soils have silica-sesquioxide, silica-alumina, and silica-acid water ratios which lie between the limits of the values for the Cecil and the Colby colloids. They may then, without serious doubt, be considered as containing colloids which are, so far as their acid complex is concerned, intermediate in character between these two extremes. The nearest approach to the halloysitic type of acid is found in the Kirvin colloid. It is a red soil and therefore a part at least of the iron present is to be regarded as free ferric oxide. The silica-total base ratio indicates that the soil is much leached. The corresponding values for the Vernon colloid, as well as the other ratios, indicated for that soil a much closer relation to the pyrophyllic types, despite the low silica-acid water ratio. The Houston colloid is an intersting example in that its very high colloidal calcium carbonate may be assumed to keep the colloidal complex wholly saturated with bases, and by consequence make the loss of water by dehydration less marked. Its acid water is therefore exceptionally high. There is available no other comparable analyses of rendzina soils but it is probable that a similar condition exists in all such soils.

An interesting relation is also found in comparing the hydrogen-ion concentration of the soils with the silica-base ratios of the colloids. The highly acid soils are the A and B horizons of the Kirvin, Cecil (*16*), and Nacogdoches (table 1), with a range between the limits of 3.8 to 5.3; and the Muskingum, Clinton (table 1), and Marshall, which, excluding the C horizons, have a range of pH values from 4.7 to 5.9. Notwithstanding this relatively slight difference in pH values, the silica-base ratios of the first group range from a minimum of 12.9 in the surface layer of the Nacogdoches (pH = 5.3) to 29.4 in the fourth layer of the same soil (pH = 5.0). The mean value of the silica-base ratios of the three lateritic colloids is 20. The minimum silica-base ratio for the other three soils is 7.6 in the surface of the Marshall (pH = 5.6) and in the second layer of the Muskingum (pH = 4.8), while the maximum is 9.1 in the fourth layer of the Clinton (pH = 5.4) and in the fourth layer of the Muskingum (pH = 4.8). The mean value of the ratios for the three soils is 8.2. In these considerations the lowest layer in each soil is not included except in the case of the Cecil. It will be noted also that particularly in the Nacogdoches and

Cecil soils the silica-total base ratio is materially lower; that is, the base content is higher in the surface layer than in those beneath it. Even allowing for an influence of the organic matter out of all proportion to its quantity, two inferences are to be drawn. There is no relation between the base content of a soil colloid and the pH value of the soil. It would seem warranted also to infer that a distinct difference exists between the inorganic soil acid of the lateritic soils and the corresponding complex in soils of higher silica-sesquioxide and higher silica-water ratios. It would appear that these relationships ought to be clarified through a study of the base exchange and base-holding capacities of these colloids. This study is already under way.

EROSIONAL CHARACTERISTICS AS INDICATED BY THE PHYSICAL AND CHEMICAL DATA

The preceding discussion of chemical data relative to these soils and their colloids does not make any attempt to associate these data with the erosional characteristics of the soils, or to include pertinent material from the tables of physical data relative to erosion. However, since erosion is the chief concern of these studies, their bearing on erosion should be discussed. For this purpose the erosion ratio makes a convenient starting point. Insofar as it has been possible to check this ratio it is the best single criterion of erosion, and where information is lacking as to the actual behavior of the soil in the field, the erosion ratio may be taken as a fair guide to the behavior to be expected.

The general relations of the physical properties of the Nacogdoches, Clinton, and Muskingum soils to their erosion ratios and to their erosional behavior have already been pointed out (p. 7). It may be noted further that while the Nacogdoches has a somewhat erosive A horizon, the field behavior shows that it is somewhat less erosive than is indicated by its ratio. The character of its colloid is such that it is very permeable to water and consequently has a low relative run-off except under dashing rains. Its colloid relatively is nonplastic, as is to be expected from its high iron oxide content (apparently nonhydrous) and its low silica-sesquioxide ratio. This effect of permeability, extending as it does throughout the profile, further accentuates the effect of low run-off.

In the Clinton profile the high erosion ratio is accentuated by the low permeability (high percolation ratio) which is in large part due to the abnormally high silt content. It is also in part due to the readily dispersible character of the colloid. The cementing effect in the colloids of high silica-sesquioxide ratio is much less marked than in lateritic colloids, and is further emphasized by the low colloid content of the Clinton.

The Muskingum silt loam is the most markedly podzolic of the erosion-station soils. It is also the least mature of these soils. It is, however, extensively leached, as shown by its pH values (table 1). It might therefore be expected to be less erosive than the Clinton. That it is so is indicated by the various ratios. It is, however, much more readily eroded than ought to be expected of a soil having its general characteristics. It is probable that its exceptionally high silt content, with consequent slow percolation, is partially responsible for its somewhat high erosivity. It is also probable that the character of the colloid, which is readily dispersible, is also a contributing influ-

ence. Below 2 feet the erosion ratio increases sharply. It is to be assumed, therefore, that this soil is subject to gully erosion to a marked degree whenever initial exposure of the C horizon occurs. The depth of the soil to the parent rock is not great. Indeed, the description of the Muskingum series indicates that the normal soil depth is less than the profile investigated. The gully formations must therefore be shallow. In order to facilitate a comparison between the physical properties of the soils and the chemical characteristics of the colloids of the A horizons of all the erosion-station soils some of these have been brought together in table 6.

TABLE 6.—*The colloid content and erosion ratio of the A horizons of the erosion-station soils and certain colloid ratios*

Soil type	Erosion ratio	Colloid percentage by mechanical analysis	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$	$\frac{\text{Silica}}{\text{Water of soil acid}}$
Clinton silt loam	57.7	11.2	2.69	8.1	0.98
Kirvin fine sandy loam	50.2	5.6	2.02	17.5	1.10
Muskingum silt loam	42.1	19.9	2.26	7.8	1.21
Vernon fine sandy loam	30.3	5.2	2.65	7.0	1.16
Shelby silt loam	28.8	24.3	2.65	8.8	1.12
Cecil sandy clay loam	22.9	17.3	1.34	13.1	.64
Nacogdoches fine sandy loam	21.7	16.1	1.07	12.9	.63
Palouse silt loam	19.4	24.0	2.48	6.6	1.16
Marshall silt loam	14.2	32.4	2.91	7.6	1.23
Colby silty clay loam	13.0	32.1	3.45	6.2	1.50
Houston black clay	8.1	44.9	3.26	5.5	1.12

In table 6 the soils are arranged in the order of decreasing erosion ratio, as shown in column 2. The colloid content is an index to the general character of the soil texture. The silica-alumina and silica-soil water ratios are indices of the nature of the colloid and the silica-total base ratio indicates in a general way the extent of weathering and leaching.

A careful study of the data given in table 6 has revealed no general relationship between the erosional character of the soils and the chemical character of their colloids. That there is no readily discernible relationship is not surprising. Soil erosion, aside from its dependence upon slope, character of cover, rainfall, and season, is determined by the resultant of a large number of factors such as texture, structure, and permeability, all of which, while influenced by the kind of colloid, are more affected by its quantity. There are, however, certain relationships which are clear. The Clinton silt loam, with its high silica, high base, and moderate water content, has a low colloid content. It is relatively tremendously erosive, as compared with Nacogdoches fine sandy loam, with nearly the same colloid content but very different colloid constitution. Again, in the case of the Kirvin fine sandy loam, the low colloid content permits high erosivity, as compared with the Cecil sandy clay loam, although the retarding effect of the colloid in the Cecil is also enhanced by the low silica and low base content. Such comparisons cannot be made general, since the relatively small differences between the Kirvin and Cecil erosion ratios cannot be traced to the same influences. Other like comparisons might be made only to find that the apparent relationships do not hold generally. It may as well be admitted that the colloid composition in itself plays a secondary role in erosion.

VOLUME WEIGHT AND RELATED PROPERTIES

In pursuance of the study of the physical properties of the soils from the erosion stations it became desirable to know the field-volume weights of the soils. Several methods of determining volume weight were tried out, and the cylinder method [2] of Curry (*8*) was found to give results as accurate as the depth to which the cylinder is driven, could be measured. However, this method was not very well adapted to securing samples from widely separated stations and getting them transported to the laboratory for analysis. In lieu of this, cans were prepared of 24-gage galvanized iron, 3 inches in diameter and 2½ inches high. The bottoms were crimped and soldered on to the sides so that they were absolutely flat. The cans were fitted with tight-fitting covers. These cans were substantial enough to be driven into very stiff soil without distortion. In procuring a volume-weight sample by this method the face of the profile is exposed and a perfectly smooth surface is prepared in the middle of the horizon to be sampled. The can is forced horizontally into the soil until the inside of the bottom is flush with the face of the profile. The soil is then dug away from around the can, leaving a cone-shaped projection of soil in front of the can. The can is then removed and the cone-shaped mass trimmed off with a knife until the surface is flat and exactly flush with the top of the can. The cover is then placed on the can and the joint taped and painted with melted paraffin.

Duplicate samples of each horizon of each soil profile, and in addition duplicate samples taken by forcing the can vertically downward into the surface soil, were taken by this method and sent to the laboratory. The samples were collected by the men in charge at the various stations. The cans had previously been weighed and their volumes measured so that when they were received in the laboratory the tape and paraffin were removed, the cans weighed and placed in a drying oven at 105° C. for 48 hours. They were then cooled in a desiccator and weighed, and from these data the volume weight and moisture content were calculated. Since all of the samples were taken in duplicate, one of each of the duplicate samples was removed from the can, rolled to pass a 2-millimeter sieve, and used for the specific-gravity determination. The remainder of the samples are being held for further study. The results of the volume-weight determinations are presented in table 7, column 3.

[2] The cylinder was made of good grade steel tubing, 3 inches in diameter, 0.08 inch thick, and 13 inches long; 0.02 inch was machined off the inside and outside to 1 inch from the cutting edge which was tapered from the original outside wall to within 0.01 inch of the original inside wall and casehardened. This left the main cylinder wall 0.04 inch thick. A steel band one-half inch wide and one-eighth inch thick was shrunk on to the cylinder at the top for the insertion of the driving plug, and to prevent collapse of the wall while being driven. The cylinder was polished inside and out and owing to the thinness of the wall and the baffle on both the inside and outside, there was no detectable amount of compression of the soil.

TABLE 7.—*Field volume weights of erosion-station soils and related data*

Sample and location	Depth to center of can (inches)	Volume weight	Specific gravity	Porosity	Moisture content	Calculated moisture content at saturation	Calculated weight of an acre-inch of soil [1]
				Percent by volume	*Percent by weight*	*Percent by weight*	*Tons*
Kirvin fine sandy loam, Tyler, Tex.	Surface	1.87	2.66	29.7	7.8	15.9	211.9
	6	1.73	2.69	35.7	11.7	20.6	196.0
	18	1.31	2.81	53.4	30.4	40.7	148.4
	30	1.48	2.85	48.1	29.8	32.5	167.7
	40	1.44	2.77	48.0	30.7	33.3	163.2
Nacogdoches fine sandy loam, Tyler, Tex..	Surface	1.46	2.76	47.1	16.6	32.2	165.4
	5	1.62	2.86	43.4	13.7	26.8	183.6
	15	1.52	2.97	48.8	24.1	32.1	172.2
	38	1.38	2.86	51.7	31.4	37.5	156.4
	72	1.24	2.99	58.5	33.0	47.2	140.5
Vernon fine sandy loam, Guthrie, Okla.	Surface	1.49	2.63	43.3	14.4	29.1	168.8
	2½	1.54	2.63	41.5	14.0	26.9	174.5
	8	1.55	2.66	41.7	13.0	26.9	175.6
	22	1.63	2.69	39.4	17.7	24.2	184.7
	38	1.61	2.69	40.2	18.8	25.0	182.4
Muskingum silt loam, Zanesville, Ohio	Surface	1.37	2.64	48.1	24.8	35.1	155.2
	3½	1.46	2.66	45.1	16.7	30.9	165.4
	9	1.41	2.70	47.8	17.0	33.9	159.8
	17	1.46	2.68	45.5	16.6	31.2	165.4
	32	1.91	2.78	31.3	13.7	16.4	216.4
	54	1.87	2.78	32.7	16.3	17.5	211.9
Cecil sandy clay loam, Statesville, N.C.	Surface	1.49	2.66	44.0	22.3	29.5	168.8
	3	1.45	2.65	45.3	20.7	31.2	164.3
	27	1.33	2.77	52.0	28.7	39.1	150.7
	55	1.48	2.78	46.8	27.1	31.6	167.7
Shelby silt loam, Bethany, Mo.	Surface	1.41	2.62	46.2	26.1	32.7	159.8
	3½	1.43	2.62	45.4	26.0	31.7	162.0
	10	1.33	2.66	50.0	26.3	37.6	150.7
	13	1.30	2.69	51.7	31.1	39.8	147.3
	16	1.43	2.70	47.0	26.6	32.9	162.0
	22	1.72	2.65	35.1	17.5	20.4	194.9
	36	1.77	2.72	34.9	15.1	19.7	200.6
	54	1.85	2.71	31.7	13.4	17.1	209.6
	72	1.85	2.71	31.7	13.3	17.1	209.6
Palouse silt loam, Pullman, Wash.	Surface	1.38	2.64	47.7	20.6	34.5	156.4
	10	1.35	2.71	50.2	20.2	37.2	153.0
	26½	1.51	2.73	44.7	22.0	29.6	171.1
	48½	1.65	2.73	39.6	19.3	24.0	187.0
	68½	1.71	2.73	37.4	17.8	21.9	193.8
	79½	1.63	2.73	40.3	18.1	24.7	184.7
Colby silty clay loam, Hays, Kans.	Surface	1.13	2.65	57.4	16.3	50.8	128.0
	5	1.35	2.64	48.9	20.4	36.2	153.0
	15	1.40	2.68	47.8	15.8	34.1	158.6
	26	1.46	2.69	45.7	16.2	31.3	165.4
	40	1.48	2.68	44.8	15.1	30.3	167.7
	53	1.40	2.69	48.0	18.0	34.3	158.6
	66	1.57	2.69	41.6	17.5	26.5	177.9
Clinton silt loam, La Crosse, Wis.	Surface	1.26	2.62	51.9	25.5	41 2	142.8
	4½	1.27	2.64	51.9	27.0	40.9	143.9
	18	1.44	2.70	46.7	22.3	32.4	163.2
	30	1.49	2.71	45.0	17.6	30.2	168.8
	45	1.80	2.70	33.3	14.0	18.5	203.9
	59	1.46	2.81	48.0	26.5	32.9	165.4
Marshall silt loam, Clarinda, Iowa	Surface	1.16	2.63	55.9	25.5	48.2	131.4
	6½	1.15	2.64	56.4	27.5	49.0	130.3
	18½	1.06	2.67	60.3	28.1	56.8	120.1
	34½	1.11	2.69	58.7	28.1	52.8	125.8
Houston black clay, Temple, Tex.	Surface	1.03	2.64	61.0	24.5	59.2	116.7
	4	1.01	2.65	61.9	27.0	61.3	114.4
	11	1.27	2.67	52.4	22.7	41.2	143.9
	20	1.51	2.69	43.9	18.8	29.1	171.1
	35	1.62	2.71	40.2	15.6	24.8	183.6

[1] The weight of an acre-inch of soil in tons is equal to 113.31× the volume weight.

The soils are listed in table 7 in the order of decreasing volume weight of the first horizon. This arrangement places the light-textured sandy soils at the top of the list, with high volume weights, while the heavy-textured clay soils are at the bottom of the list with low volume weights. Aside from this, there is no correlation between

the texture of the soil and the volume weight, or between the volume weight and the specific gravity. The range in volume weight is quite large—from 1.01 in the first horizon of the Houston to 1.91 for the fourth horizon of the Muskingum. In 6 cases the surface sample agrees fairly well with the first horizon and in 5 cases the divergence is markedly either more or less, the greatest difference being shown by the Colby—1.13 for the surface and 1.35 for the first horizon. However, the writers do not place much confidence in the results for the surface samples owing to greater difficulty in getting uniform samples at the surface as compared with the lower horizons.

The Nacogdoches and Houston profiles are of particular interest. The volume weight of the Nacogdoches decreases from 1.62 in the first horizon to 1.24 in the fourth horizon, while the Houston increases from 1.01 in the first horizon to 1.62 in the fourth horizon. In the same order, the porosity and moisture content increase in the Nacogdoches and decrease in the Houston. This would indicate that the Nacogdoches is much better drained than the Houston, owing to the greater capacity for water in the lower horizons. This may also aid in explaining the low erosion of the Nacogdoches.

The Clinton, Colby, Palouse, and Vernon soils show the same general trend toward higher volume weights in the lower horizons as the Houston, although in each of these cases there is one horizon which is out of order to make a straight gradation. The Marshall, Muskingum, Shelby, Cecil, and Kirvin soils all have higher volume weights in the first than in the second horizons, and in general the volume weights of their various horizons are quite irregular.

So far as the writers are aware, the relation between the volume weight of soils and their erosional behavior has not been discussed elsewhere. It would appear that when such wide differences in weight appear as are shown by the surface and A horizons of the Kirvin and Houston soils such difference ought to have an apparent effect on erosion. The soil of the greater volume weight might be expected to be less readily brought into suspension and, other things being equal, should settle more rapidly through a viscous medium. If such result does occur, it is effectively masked by other relations. The Kirvin is, of all the erosion soils, the most readily dispersed, and is one of the most readily eroded. The volume weight of the soils has, however, a very significant importance in erosional considerations, as will be pointed out later.

The specific gravity of soils has, besides a direct interest, additional value because of its value in calculating the porosity of soils. The specific gravity of all horizons of the erosion-station soils was determined. The usual pyknometer method was employed with water as a menstrum. The resulting data are found in table 7, column 4. In each profile there is an increase in specific gravity with depth. This increase is probably due in large part to the decrease in organic matter. Such relation is by no means shown with the volume weights. The soils differ materially from each other. The greatest specific gravity is shown by the 72-inch sample of the Nacogdoches fine sandy loam, 2.99. It is of interest to note that the volume weight of this layer is but 1.24 and is the lowest volume weight for the profile. The lowest specific gravity of any of these samples is shown by the surface samples of the Clinton and Shelby soils. While it is true that in general the more highly weathered soils have the highest specific

gravity, there is no direct relation detectable, either with the quantity or character of colloid. It is of passing interest to note that the conventionally used mean specific gravity of soils, 2.65, is fairly well maintained by these 11 profiles, the mean value being 2.71. The mean value for the 22 samples representing the upper horizons is 2.66.

From the data on the field volume weight and the specific gravity the porosity of the soil may be calculated. The porosity is defined as the percentage by volume of the soil which is unoccupied by soil particles. This space may, in the field, be occupied either by air or by water or partly by air and partly by water. The formula used for the calculation is:

$$\frac{S-A}{S} \times 100 = \text{porosity},$$

where S = specific gravity and A = volume weight (apparent specific gravity). The resulting values are in column 5 of table 7. The porosity range in the 11 profiles is between the limits 29.7 percent for the surface sample of the Kirvin fine sandy loam and 61 percent for the surface of the Houston black clay and 61.9 percent for the A horizon. There is no uniform behavior of the soils with respect to porosity within each profile, although in general the relation holds that increase of colloid content is accompanied by increase in the porosity. There does not appear to be a quantitative relation.

In column 6 of table 7 are given the moisture content of the samples, as received from the stations. The men in charge of the various stations were requested to collect these samples when in their judgment the soil was at its maximum field carrying capacity; or, as soon after the winter rains as the soil could be considered as having been freed from gravitational water and not appreciably dried by surface evaporation. It was not possible to meet this condition in every case, nor in all cases within a single profile. In general, however, the moisture percentages represent the normal field carrying capacity fairly well. The data in column 7 are in weight percentage.

In column 7 of table 7 is presented the calculated moisture content at saturation in percentage by weight. The quantity is obtained by dividing the porosity by the volume weight. This quantity represents the percentage by weight of the moisture in the soil when all the pore space is filled with water. It seems to the writers that this value gives a better expression of pore space than does porosity, since soil workers are, as a rule, more familiar with weight than with volume relations. For example, the 54-inch sample of the Muskingum soil has a porosity of 32.7 percent by volume and a moisture content of 16.3 percent. This relation does not make apparent at a glance to what degree the soil approaches saturation. The saturation-weight percentage in column 7 is 17.5 percent and consequently since the sample contains 16.3 percent it is very nearly saturated. Indeed, it is probable that under field conditions a soil is practically never saturated in the sense that no part of its pore space is occupied by air. The nearest approach to saturation in this sense in the series of soils under examination is the 40-inch sample of the Kirvin fine sandy loam, which contains 30.7 percent moisture or 92.2 percent of its saturation capacity.

In connection with the work of the erosion experiment stations it is desired to express the rate of erosion in terms of the periods of

time required, at a given rate, to remove the A horizon partially or completely. What is measured is the tons of material per acre. In making such calculations it is usual to use an arbitrarily selected mean value of 4,000,000 pounds per acre-foot, or 2,000,000 pounds for the plow depth taken as 6⅔ inches. It would be better if the actual weight per acre-foot for each soil were known, or, perhaps more conveniently, the weight per acre-inch. In table 7, column 3, is given the volume weight of each portion of the soil profiles and from this may be calculated the weight per acre-inch. The formula used in the calculation is:

$$\frac{16.3872 \times 144 \times 43{,}560}{453.59 \times 2{,}000} = 113.3 \text{ tons},$$

in which 16.3872 is the number of cubic centimeters per cubic inch, 43,560 = the number of square feet per acre, and 453.59 = the number of grams per pound. An equally applicable formula is:

$$\frac{62.424 \times 43{,}560}{12 \times 2{,}000} = 113.3 \text{ tons}.$$

The value 113.3 tons is the weight of an acre-inch of water and therefore 113.3 × the volume weight (apparent specific gravity) is the weight of an acre-inch of dry soil. In column 8 of table 7 are given the resulting weights per acre-inch of each profile sample.

It may be questioned whether these calculations are based upon an adequately accurate volume weight. It must be conceded that they are more satisfactory than an arbitrarily selected average figure. It will be seen that they range from a maximum value of 216.4 tons per acre-inch for the 32-inch sample of the Muskingum to 114.4 tons for the 4-inch sample of the Houston. Also, the variations between successive layers are so great at times as to make somewhat doubtful the estimation of the weight of an acre-foot. It is interesting, however, to note that if we take the mean value of the surface and A horizon samples and multiply each by 12 the extreme quantities are 1,386.6 tons or 2,793,200 pounds, and 2,447.4 tons or 4,894,800 pounds per acre-foot. Yet if we take the mean of all the corresponding values for the 22 surface samples (the surface samples and the A horizon) the value per acre-foot becomes 1,879.56 tons or 3,759,120 pounds per acre-foot. When it is considered that the erosion station soils do not represent sands at all, and also not the extreme organic or highest clay soils, the results are a good confirmation of the conventional 4,000,000 pounds per acre-foot.

An additional point of interest is the fact that the A horizon of the soils is a variable quantity and therefore the quantity in tons representing the removal of the A horizon by erosion will vary not only with the soil weight per acre-foot but with the depth of the horizon. It is perhaps not essential to carry out calculations in full to show this. An example will suffice. On the basis of the above data the A horizon, or surface soil, of the Kirvin fine sandy loam, with a depth of 12 inches, represents a soil weight of 2,352 tons per acre, while the Cecil sandy clay loam, with an A horizon of but 6 inches, represents a weight of but 986 tons, and the Houston black clay, depth 8 inches, represents 915 tons.

SETTLING VOLUME AND RELATED PROPERTIES

When soils are thoroughly mixed with a small excess of water and allowed to stand for 24 hours or more, they settle to a definite volume, leaving a clear supernatant liquid or one faintly opalescent with colloid. This volume is greater by far than the field volume of the dry soil. In a study of this soil property, which has been called the settling volume of soils, of the erosion-station soils, it was noted that the volume was quite different for the various soils, when comparison was made under strictly comparable conditions. A report upon this property of the erosion-station soils has been made by Middleton and Byers (*15*). The essential portions of this bulletin, together with certain additional data, are included in this discussion.

The settling volume is defined as the maximum volume that a given quantity of soil can maintain in an excess of water under specific conditions. The water content of the soil at the settling volume has

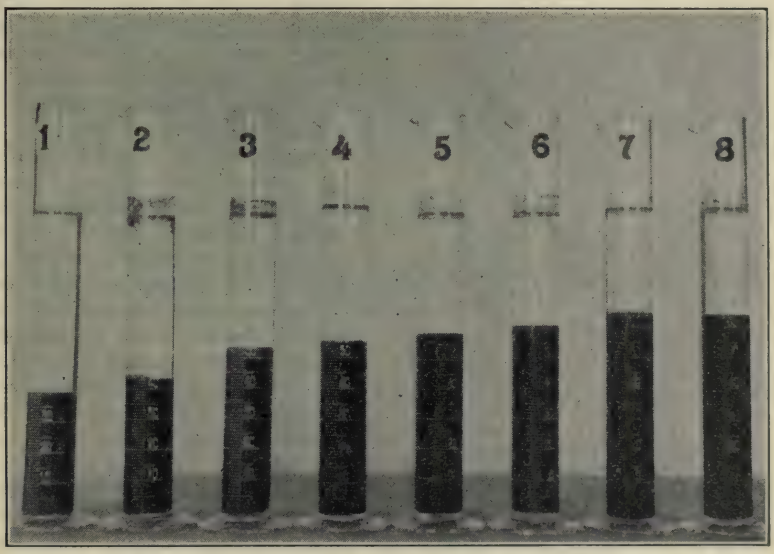

FIGURE 1.—Settling volumes of A horizons. 1, Kirvin fine sandy loam; 2, Vernon fine sandy loam; 3, Cecil sandy clay loam; 4, Shelby silt loam; 5, Palouse silt loam; 6, Colby silty clay loam; 7, Marshall silt loam; 8, Houston black clay.

been designated as the water-saturation capacity. This quantity obviously represents the maximum water content of a soil-water equilibrium system.

The settling volume is determined as follows: A quantity of air-dry soil, equivalent to 50 g of oven-dry soil, is placed in a 250-cc beaker and 35 to 40 cc of water is added. The soil and water are vigorously stirred and the beaker placed in a vacuum desiccator and evacuated until the mixture boils vigorously. The mixture is poured into a 100-cc graduate, with the minimum quantity of water required for rinsing the beaker. The resulting volume is usually about 90 cc. The graduate is covered by the palm of one hand and shaken vigorously. It is then set on the table, the inside washed down with a fine jet of water, and the volume made up to 100 cc. The suspension is allowed to

stand for 24 hours, and the soil volume noted. The graduate is again shaken and allowed to stand 24 hours. The process is repeated until a constant volume is reached; this obtains usually after 3 or 4 shakings. The volume is noted to the nearest 0.5 cc. Duplicates agree within 1 cc and the difference is seldom so great. The line between soil suspension and water is very sharp. Occasionally there is a suspension of colloid of small magnitude in the supernatant liquid, but when it finally clears, the flocculated material seldom changes the volume by more than 1 cc. On long standing, indeed for several weeks, the volume of the suspension does not change materially.

An illustration of the relationships shown by different soils when treated as described is shown in figure 1.

The settling volumes of the first 2 horizons of the 11 soils were carefully determined. The results are found in table 8, column 4.

In table 8 the soils are listed in the order of increasing settling volumes of the A horizons. This places them practically in the same order as in table 7, where they are placed in the order of decreasing volume weights of the first horizons. Included in table 8 are the colloid content by water-vapor absorption, (column 5) the moisture equivalent (column 6), and the water-saturation capacity (column 7). This last quantity is calculated by subtracting the absolute volume of the soil from the settling volume and dividing this difference, which numerically corresponds to the weight of the water present, by the weight of the soil. The quotient times 100 gives the "water-saturation capacity" expressed in percentage. This term may not be well chosen because of its similarity to the term "maximum water-holding capacity" as used by Hilgard, but no better term has occurred to the writers. In column 8 is given the volume weight of the soil in suspension. The quantities are calculated by dividing the weight of the soil by the settling volume. They represent the minimum volume weight the soil is able to maintain in the presence of water. Since the field volume weight of the soils represents an approach toward this condition, the field volume weights of the corresponding horizons, as given in table 7, are also given in column 9. The field volume weights are in every case much higher than the minimum volume weight of the soil in suspension, yet there is a rather close correlation between the two values. This relation may be brought out more clearly by plotting the data as in figure 2.

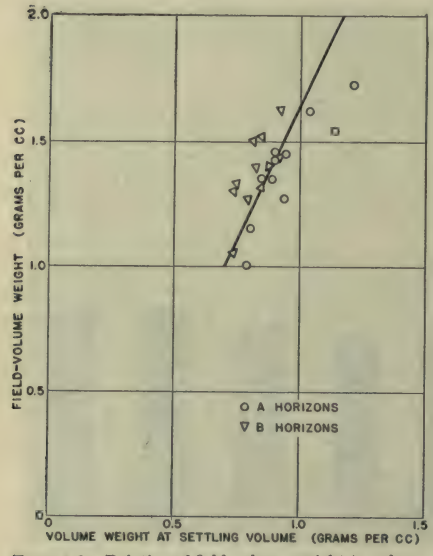

FIGURE 2.—Relation of field volume weight to volume weight at settling volume.

In figure 2 the field volume weights are plotted as ordinates and the settling volume weights as abscissae. Were the correlation perfect, these points would, of course, lie upon the same line. They do not,

but the deviation is not great. If a median line be drawn between the points it will be observed that all of the A horizon points, except one, are on one side of the line, while all the B horizon points, save one, are on the other side. This occurs because in all cases, except the Houston, the settling volume of the A horizon is more dense than the corresponding B horizon. This is probably owing to the fact that the B horizon has a greater colloid content than the A horizon. In the field, volume weights of the B horizon are sometimes greater and sometimes less than in the A horizon. In this connection preliminary experiments in this laboratory indicate that repeated wetting and drying of soils under certain conditions produce a maximum volume which, at least in some soils, approaches closely the settling volume of soils.

If, in a similar manner, the relation between the settling volume of these soils and the colloid content (column 5, table 7) is considered, it

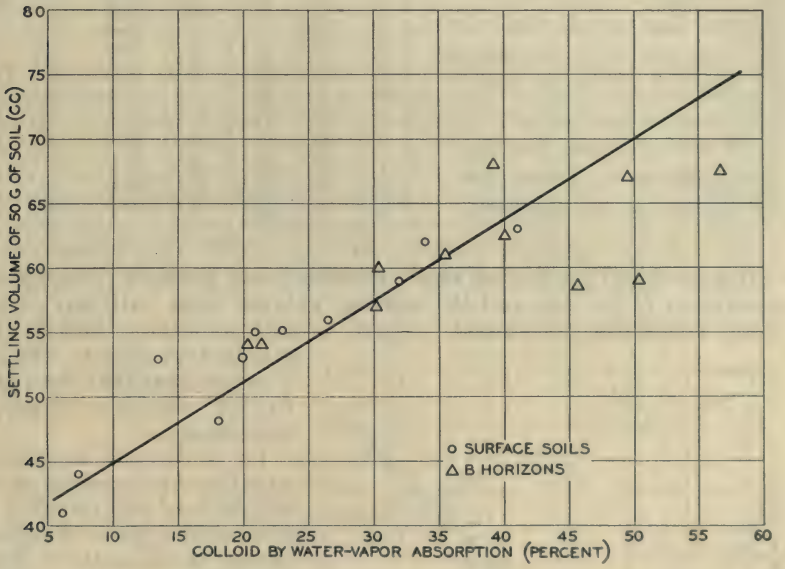

FIGURE 3.—Relation of the settling volume to the colloid by water-vapor absorption.

is to be observed that in general the settling volume increases with the colloid content. The correlation is far from quantitative, as indicated by figure 3.

The divergence of the points from any specific line is quite marked. It may properly be concluded that some other and quite definite factor than colloid content is of moment in determining the settling volume, although unquestionably the quantity of colloid is of considerable importance.

The moisture equivalent of soils is a property of soils which, while largely dependent upon the kind and quantity of colloid is considerably modified by the general textural composition. Inspection of the settling volume values (column 4, table 8) as related to the moisture

equivalent again indicates a general correlation. If these values are plotted, as before, the result indicated in figure 4 is obtained.

TABLE 8.—*Settling volume of profile samples*

Sample no.	Soil type and location	Horizon	Settling volume	Colloid by water-vapor absorption	Moisture equivalent	Water saturation capacity	Volume weight of soil in suspension on dry basis	Field volume weight
			Cc	*Percent*	*Percent*	*Percent*	*Grams per cc*	*Grams per cc*
6678	Kirvin fine sandy loam, Tyler, Tex.	A	41	5.9	7.9	45.0	1.22	1.73
6679		B	67½	56.6	30.5	98.8	.74	1.31
6718	Vernon fine sandy loam, Guthrie, Okla.	A	44	7.4	9.6	50.2	1.14	1.54
6720		B	54	21.5	17.7	70.8	.93	1.63
9475	Nacogdoches fine sandy loam, Tyler, Tex.	A	48	18.6	14.3	59.6	1.04	1.62
9476		B	59	50.5	25.2	83.0	.85	1.52
10362	Clinton silt loam, La Crosse, Wis.	A	53	13.7	23.9	68.0	.94	1.27
10363		B	54	20.3	23.5	71.0	.93	1.44
6977	Cecil sandy clay loam, Statesville, N.C.	A	53	20.0	20.0	68.0	.94	1.45
6978		B	58½	45.7	26.6	80.4	.86	1.33
B407	Muskingum silt loam, Zanesville, Ohio.	A	55	21.0	25.5	72.6	.91	1.46
B408		B	57	30.4	26.2	77.6	.88	1.41
6797	Shelby silt loam, Bethany, Mo.	A	55	23.1	24.5	72.0	.91	1.43
6798		B	67	49.6	34.9	86.8	.75	1.33
8069	Palouse silt loam, Pullman, Wash.	A	56	26.4	25.1	74.6	.89	1.35
8070		B	61	35.6	27.8	85.4	.82	1.51
6842	Colby silty clay loam, Hays, Kans.	A	59	32.1	27.3	80.0	.85	1.35
6843		B	60	30.7	25.2	82.6	.83	1.40
8736	Marshall silt loam, Clarinda, Iowa.	A	62	33.9	30.1	86.0	.81	1.15
8737		B	68	39.4	31.8	98.4	.74	1.06
6096	Houston black clay, Temple, Tex.	A	63	41.1	30.5	88.4	.79	1.01
6097		B	62½	40.2	27.6	87.8	.80	1.27

It is obvious that a much closer relation exists between the moisture equivalent of the soil and the settling volume than with any of the other properties considered. There is still something lacking for satisfactory results, though it seems clear that the quantity of colloid is of major importance.

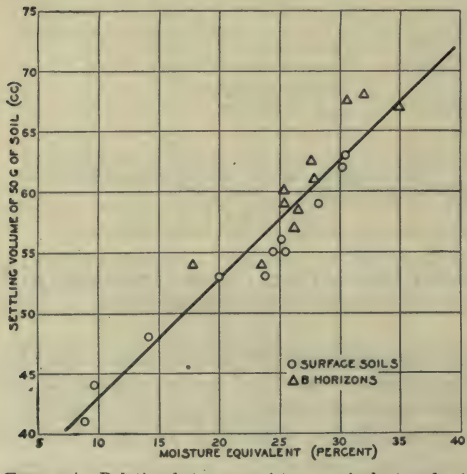

FIGURE 4.—Relation between moisture equivalent and settling volume.

In order to determine whether the character of the colloid is of any moment in determining the settling volume of the soils the colloids of 9 of the erosion-station surface soils were obtained and their settling volumes determined exactly as for the soils except that only 10 g of colloid were employed. The quantity of colloid is not important in showing relative settling volumes, as indicated by the Shelby silt loam. Samples of this colloid of 5, 10, and 25 g were used with 100 cc of water, and the settling volumes obtained were 11, 21.5, and 53 cc, respectively. The results obtained with the nine colloids used are found in table 9, together with their specific gravity and the silica-sesquioxide ratios. From the settling volume and specific gravity of

these colloids the water-saturation capacity and apparent specific gravity (volume weight in suspension) are calculated.

TABLE 9.—*Settling volume of colloids from the A horizons of the erosion-station soils and related properties*

Soil from which colloid was extracted	Settling volume	Specific gravity	Silica-sesquioxide ratio	Water-saturation capacity	Volume weight of soil in suspension on dry basis
	Cc			*Percent*	
Nacogdoches fine sandy loam	16.0	2.92	1.07	126	0.63
Cecil sandy clay loam	19.0	2.69	1.34	153	.52
Kirvin fine sandy loam	18.5	2.75	2.02	147	.54
Shelby silt loam	21.5	2.64	2.65	177	.47
Palouse silt loam	22.0	2.69	2.48	183	.45
Marshall silt loam	22.0	2.62	2.91	182	.45
Clinton silt loam	22.5	2.60	2.69	187	.44
Colby silty clay loam	24.5	2.67	3.45	208	.41
Houston black clay	26.0	2.67	3.26	223	.38

The data of table 9 reveal at once a definite relation between the composition of the colloids, as shown by their silica-sesquioxide ratios and their settling volumes. The colloids of the lateritic type are in general of low settling volume and the high silica-sesquioxide ratios have greatly increased water-saturation capacities. The wide variation of the different colloids in respect to settling volume also indicates a dependence of these volumes upon the character of the colloid and consequently their effect upon the settling volume of soils. When an attempt is made to establish a definite relation by plotting the

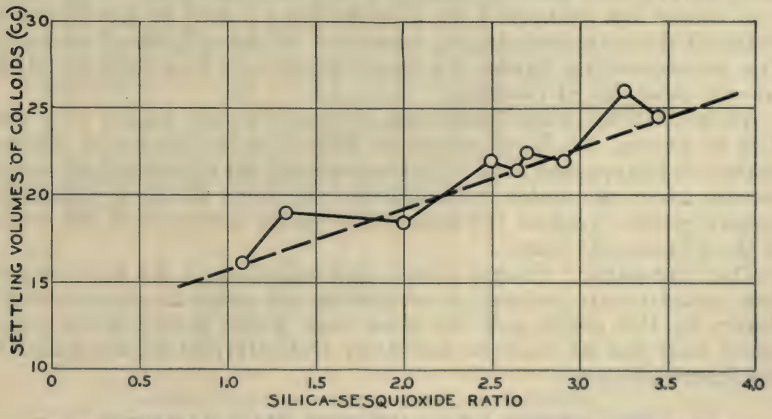

FIGURE 5.—Relation of the settling volume of the colloids to their silica-sesquioxide ratios.

settling volume relations against the silica-sesquioxide ratios, the results are as shown in figure 5.

It is quite clear that while the settling volume of the colloids is, to a degree, dependent upon the composition of the colloids, yet that composition is not wholly expressed by the silica-sesquioxide ratio. That a relationship exists between the composition of colloids and their water relationships has already been pointed out by Anderson and Mattson (*3*) and the nature of the differences in composition giving

rise to these differences has been discussed by Byers (*7*). The data on water of composition of the soil acids given in tables 4 and 5 are not sufficiently accurate to be used in this connection.

It may then be concluded that the settling volume of the soils is a soil property which depends in part upon the constitution of the colloid, the quantity of colloid and upon the other textural properties. It seems at present impossible more closely to define the contributing influences.

The relation of the settling volume to the water-saturation capacity has already been mentioned (p. 25), and the value has been determined for the 11 erosion-station soils. The water-saturation capacity represents the greatest quantity of water which may remain in equilibrium with the soil. This quantity cannot, of course, be found in any field sample but the condition represented by it must be approached when, under very heavy rain, the surface of a soil reaches the condition described by the term "quagmire." It must also be similar to the situation which obtains at the bottom of still ponds into which eroded material has been discharged. The relation of this soil property to certain other soil-water relations which have been determined for these soils is of particular interest. It is perhaps best shown graphically as in figure 6.

The soils in figure 6 are arranged in the order of increasing water-vapor-absorption values; that is, in the order of increasing colloid content of the A horizons. The spaces between successive soils are not proportional to any quantity but are arbitrarily made equal. The percentage content of water at the moisture equivalent, maximum water-holding capacity, and water-saturation capacity of the same horizons are then plotted upon the perpendicular axis. The successive values are connected by straight lines. Also in the figure are included the water-saturation capacities of the colloids of nine soils. The corresponding figures for the Vernon and Muskingum colloids are not available at present.

An inspection of the graph (fig. 6) for the soils makes very clear that in general the same influences determine all the water relationships. It is apparent that both the composition of the colloid and the texture affect the water relationships. Perhaps the most interesting feature of the graph is the abnormally great influence of the colloid of the Clinton silt loam.

That the settling volume of soils and colloids and the water-saturation capacities are real and determinable soil properties is abundantly shown by this graph and the data from which it is derived. How useful they can be made in soil study and interpretation remains for the future to show.

PROPERTIES OF COMPOSITE PLOT SAMPLES

In the previous report (*16*) are given the data for the composite plot samples of the Houston, Cecil, Kirvin, Vernon, Shelby, and Colby soils. Herewith the data are given for the Palouse, Marshall, Nacogdoches, and Clinton soils. This completes the series except for the Muskingum, the samples of which have not been received. As in the previous case (*16*) these samples were subjected to the following determinations: Colloid by water-vapor absorption, moisture equivalent, dispersion ratio, and complete mechanical analysis. From

the results of these determinations the colloid-moisture equivalent ratio and the erosion ratio were calculated. The average value of each determination for all the plots (except desurfaced plots) at each

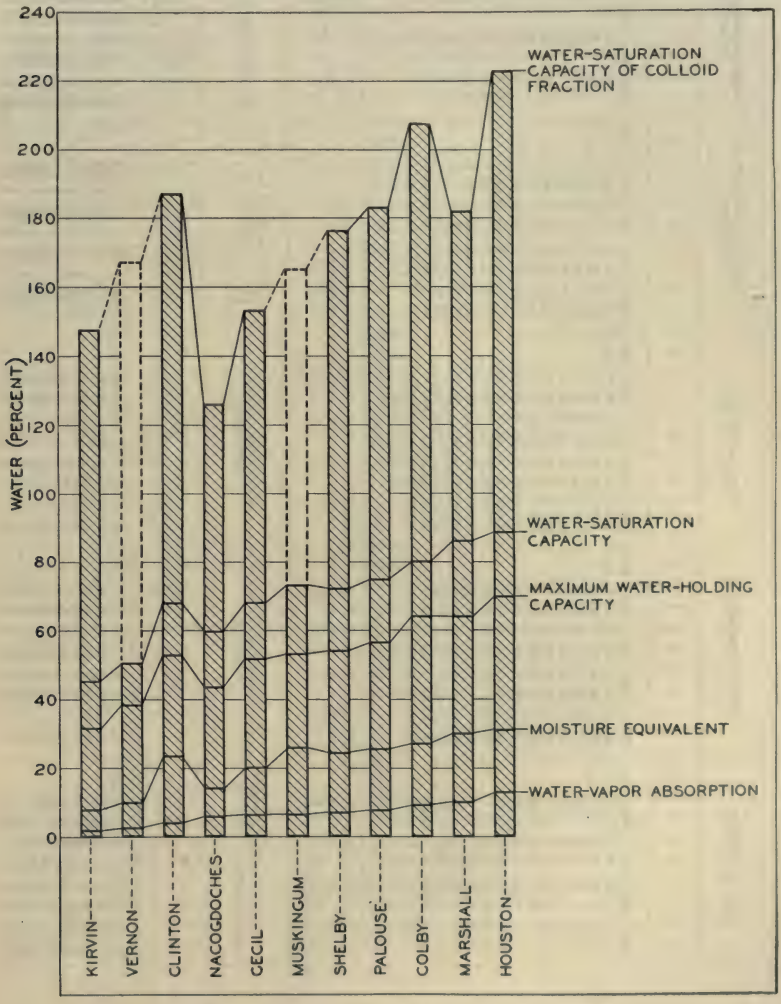

FIGURE 6.—Water relationships of the erosion-station soils.

station was computed for each horizon, and the standard deviation and the coefficient of variability were calculated. The data for the four soils are given in tables 10, 11, 12, and 13.

TABLE 10.—*Analyses of plot composite samples, by horizons, from Palouse silt loam* [1]

Plot no.	Sand in horizon—					Silt in horizon—					Clay in horizon—					Colloid <0.002 mm in horizon—					Organic matter by H_2O_2 in horizon—				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
P [2]	6.4	5.9	6.0	7.2	6.6	64.0	55.6	58.2	63.0	64.0	27.5	37.5	35.4	29.8	29.2	24.0	33.8	32.0	26.6	25.9	1.8	0.8	0.1	0.0	0.0
1 [3]	7.9	7.0	6.4	7.1	____	63.2	60.4	56.0	55.2	____	26.6	30.6	36.5	36.8	____	22.7	25.3	31.3	32.0	____	1.8	1.5	.9	.5	____
2 [4]	7.2	7.4	5.6	6.0	____	61.2	58.1	57.4	58.0	____	29.6	32.8	36.0	35.1	____	24.5	28.0	31.5	32.1	____	1.7	1.3	.8	.4	____
3	7.7	7.1	5.9	5.0	____	60.1	59.5	56.7	55.1	____	30.1	31.4	36.4	39.3	____	24.0	28.3	33.6	33.7	____	1.7	1.6	.7	.4	____
4	7.5	6.8	6.1	5.6	____	62.2	61.0	56.9	56.7	____	28.4	30.6	36.2	37.2	____	22.8	25.6	29.8	34.0	____	1.7	1.3	.8	.3	____
5	8.7	6.7	6.2	5.2	____	58.9	61.5	58.4	57.2	____	30.4	30.4	34.8	37.3	____	25.2	25.9	30.8	32.7	____	1.4	1.1	.4	.2	____
6	7.1	6.4	5.8	5.6	____	62.1	60.8	57.7	55.5	____	28.8	31.5	35.8	38.4	____	22.8	27.7	30.4	33.0	____	1.5	1.0	.3	.0	____
7	9.2	6.0	6.6	5.6	____	58.5	62.8	57.2	57.5	____	29.7	29.4	35.2	36.0	____	21.7	26.3	30.0	32.6	____	2.0	1.5	1.0	.6	____
8	6.3	6.3	7.0	6.1	____	63.6	61.3	59.1	56.6	____	27.9	30.7	32.7	36.7	____	23.6	27.5	31.6	32.6	____	2.0	1.4	1.0	.4	____
9	6.3	6.8	5.7	5.7	____	62.0	60.1	57.3	56.4	____	29.8	31.5	36.1	37.6	____	23.8	26.6	30.8	33.8	____	1.5	1.2	.6	.3	____
10	5.9	6.4	5.8	5.6	____	64.2	61.8	58.0	55.7	____	27.7	30.0	35.1	38.3	____	21.5	26.1	27.9	34.2	____	1.9	1.4	.7	.1	____
11	7.1	6.1	6.2	4.8	____	63.2	63.3	62.2	58.2	____	27.8	28.7	30.5	36.5	____	22.8	22.4	29.0	31.7	____	1.6	1.7	.9	.2	____
12	6.4	6.0	6.1	5.9	____	64.2	64.1	60.3	55.2	____	27.5	28.2	31.5	37.9	____	23.1	24.4	27.9	33.3	____	1.7	1.6	.7	.5	____
13	6.8	6.5	6.6	6.0	____	62.9	61.4	59.5	55.5	____	28.3	30.5	33.0	38.0	____	27.8	29.0	28.3	33.1	____	1.6	1.2	.5	.2	____
14 [5]	____	5.8	6.0	6.2	5.6	____	60.0	59.1	55.8	49.5	____	33.0	33.8	37.3	44.5	____	28.9	30.7	33.8	38.2	____	.8	.7	.3	.1
15 [6]	6.8	6.8	8.0	6.9	5.9	55.6	55.6	59.4	57.7	55.6	36.3	37.2	31.6	34.4	37.8	32.4	32.4	27.8	29.5	32.5	____	____	____	____	____
Average [7]	7.2	6.6	6.2	5.7	____	62.0	61.2	58.2	56.4	____	28.7	30.5	34.6	37.3	____	23.6	26.4	30.2	33.0	____	1.7	1.4	.7	.3	____
Standard deviation	.9	.4	.4	.5	____	1.8	1.5	1.6	1.1	____	1.1	1.2	1.9	1.1	____	1.6	1.7	1.6	.8	____	.2	.2	.2	.2	____
Coefficient of variability	12.9	6.4	6.4	9.6	____	2.9	2.5	2.8	1.9	____	3.9	3.9	5.6	2.9	____	6.7	6.5	5.3	2.3	____	10.6	14.4	30.2	55.5	____

Plot no.	Colloid by water-vapor absorption in horizon—					Moisture equivalent in horizon—					Dispersion ratio in horizon—					Ratio of colloid to moisture equivalent in horizon—					Erosion ratio in horizon—				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*																
P [2]	26.4	35.6	35.8	30.4	30.8	25.1	27.8	27.6	25.5	25.5	20.4	16.2	21.6	28.6	26.2	1.05	1.28	1.30	1.19	1.21	19.4	12.7	16.6	24.0	21.7
1 [3]	25.5	30.4	37.0	38.6	____	24.1	26.2	27.6	27.9	____	30.8	19.9	22.7	26.9	____	1.06	1.16	1.34	1.38	____	29.1	17.2	16.9	19.5	____
2 [4]	26.2	29.4	34.2	35.1	____	24.9	26.3	27.6	28.0	____	31.3	18.4	24.8	29.3	____	1.05	1.12	1.24	1.25	____	29.8	16.4	20.0	23.4	____
3	25.2	29.2	33.9	37.2	____	24.8	25.7	27.2	28.8	____	35.5	22.4	25.3	27.7	____	1.02	1.14	1.25	1.29	____	34.8	19.6	20.2	21.5	____
4	25.6	28.7	34.3	37.0	____	25.2	25.8	27.7	28.4	____	33.4	21.1	22.2	28.4	____	1.02	1.11	1.24	1.30	____	32.7	19.0	17.9	21.8	____
5	25.5	27.4	32.8	36.3	____	24.6	25.8	27.5	28.5	____	25.3	16.5	18.8	20.7	____	1.04	1.06	1.19	1.27	____	24.3	15.6	15.8	16.3	____
6	24.8	28.0	33.1	36.3	____	24.7	26.2	28.0	28.4	____	25.5	19.3	22.9	28.0	____	1.00	1.07	1.18	1.28	____	25.5	18.0	19.4	21.9	____
7	24.6	27.4	32.7	36.6	____	24.9	26.1	27.8	28.5	____	30.2	20.2	20.0	22.5	____	.98	1.05	1.18	1.28	____	30.8	19.2	16.9	17.6	____

8	25.3	28.8	33.0	36.6		25.0	26.1	27.7	28.5		29.8	21.9	26.0	30.6		1.01	1.10	1.19	1.28		29.5	19.9	21.8	23.9	
9	24.6	26.7	32.1	36.5		25.2	26.0	26.8	28.4		31.1	23.5	21.1	27.2		.98	1.03	1.20	1.29		31.7	22.8	17.6	21.1	
10	25.4	26.9	31.2	36.1		23.8	25.0	26.8	27.9		30.3	19.6	21.2	27.4		1.07	1.08	1.16	1.29		28.3	18.1	18.3	21.2	
11	24.4	26.4	31.3	37.0		24.6	25.6	27.1	28.7		34.8	24.5	21.0	23.1		.99	1.03	1.16	1.29		35.2	23.8	18.1	17.9	
12	26.1	27.6	30.9	36.9		24.9	25.9	26.8	28.6		30.1	28.8	21.0	24.0		1.05	1.07	1.15	1.29		28.7	26.9	18.3	18.6	
13	25.4	27.8	32.0	38.4		24.2	25.2	25.6	28.0		28.7	21.1	22.7	26.7		1.05	1.10	1.25	1.37		27.3	19.2	18.2	19.5	
14 [5]		29.8	30.2	34.7	34.4		25.6	25.9	27.1	27.0		25.2	24.3	24.2	31.2		1.16	1.17	1.28	1.27		21.7	20.8	18.9	24.6
15 [6]	31.5	33.5	27.4	30.5	35.4	25.5	26.6	24.8	26.1	27.1	30.2	30.4	28.3	27.2	28.5	1.24	1.26	1.10	1.17	1.31	24.4	24.1	25.6	23.3	21.8
Average [7]	25.3	28.1	33.0	36.8		24.7	25.8	27.2	28.4		30.5	21.3	22.3	26.3		1.02	1.09	1.21	1.30		29.8	19.7	18.4	20.3	
Standard deviation	.5	1.1	1.6	.9		.4	.4	.6	.3		2.9	3.0	2.0	2.8		.03	.04	.05	.04		3.1	3.0	1.5	2.3	
Coefficient of variability	2.1	4.0	4.8	2.4		1.6	1.5	2.3	1.0		9.5	13.9	9.1	10.6		3.00	3.60	4.20	2.70		10.4	15.3	8.4	11.2	

[1] Mechanical analyses by H. W. Lakin and T. M. Shaw.
[2] Profile sample.
[3] Short plot.
[4] Long plot.
[5] Desurfaced plot.
[6] Desurfaced and refilled to original level, 1932.
[7] Average does not include profile sample or desurfaced plots.

TABLE 11.—*Analyses of plot composite samples, by horizons, from Marshall silt loam* [1]

Plot no.	Sand in horizon—				Silt in horizon—				Clay in horizon—				Colloid <0.002 mm in horizon—				Organic matter by H_2O_2 in horizon—			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
P [2]	2.1	1.5	3.5	18.1	59.0	56.5	61.6	55.2	35.3	39.4	33.8	26.5	32.4	34.6	28.2	20.3	3.2	2.3	0.8	0.0
1 [3]	2.2	1.6	1.0	1.1	60.4	60.0	58.9	63.8	34.1	35.8	37.9	33.9	29.9	32.0	33.6	28.5	3.1	2.3	1.9	.8
2 [4]	2.1	1.7	1.2	1.1	59.6	57.1	58.2	62.2	34.9	38.2	38.7	35.9	30.5	33.2	33.9	29.3	3.1	2.6	1.5	.5
3	2.4	1.6	.9	1.0	58.2	58.2	59.8	64.1	35.8	37.7	38.0	34.1	30.6	33.3	33.4	28.5	2.9	2.4	1.1	.4
4	1.8	1.7	1.2	1.0	60.4	58.5	58.7	64.4	34.5	36.8	38.3	33.8	29.7	32.4	33.1	28.3	3.1	2.6	1.7	.4
5	1.8	1.3	1.1	3.0	61.1	59.4	60.4	63.6	33.7	36.3	37.4	32.8	29.7	31.0	31.7	27.8	2.6	2.6	.7	.1
6	2.0	1.5	1.4	1.2	60.7	58.7	58.2	64.1	33.9	36.8	38.7	34.1	29.7	32.5	33.6	29.0	3.0	2.6	1.4	.0
7	2.0	1.4	1.0	.5	61.7	58.5	61.4	66.4	33.3	37.5	36.6	32.5	30.4	33.0	32.0	25.9	2.2	2.0	.8	.4
8	1.5	1.4	.9	1.0	60.7	59.6	58.6	64.2	34.6	36.3	39.2	34.2	29.9	33.4	31.2	30.8	2.3	2.1	.7	.0
9 [5]	------	1.1	.9	1.0	------	54.5	57.3	64.0	------	42.1	40.8	34.3	------	35.5	34.2	27.5	------	1.8	.7	.3
Average [6]	2.0	1.5	1.1	1.2	60.4	58.8	59.3	64.1	34.4	36.9	38.1	33.9	30.1	32.6	32.8	28.5	2.8	2.4	1.2	.3
Standard deviation	.3	.1	.2	.7	1.0	.9	1.0	1.1	.7	.8	.8	1.0	.4	.8	1.0	1.3	.3	.2	.4	.3
Coefficient of variability	13.0	9.4	15.7	58.0	1.6	1.5	1.7	1.7	2.1	2.1	2.0	2.8	1.2	2.3	2.9	4.6	12.4	9.6	36.6	86.6

Plot no.	Colloid by water-vapor absorption in horizon—				Moisture equivalent in horizon—				Dispersion ratio in horizon—				Ratio of colloid to moisture equivalent in horizon—				Erosion ratio in horizon—			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*												
P [2]	33.9	39.4	33.1	21.4	30.1	31.8	29.3	23.3	16.1	7.9	18.2	31.8	1.13	1.24	1.13	0.92	14.2	6.4	16.1	34.5
1 [3]	33.3	36.9	38.8	36.0	30.4	31.7	32.1	30.4	26.0	24.1	23.9	33.2	1.10	1.16	1.21	1.18	23.6	20.8	19.8	28.1
2 [4]	33.4	36.7	38.7	35.0	30.6	31.8	32.4	29.9	27.0	25.7	23.5	33.8	1.09	1.15	1.19	1.17	24.8	22.3	19.8	28.9
3	32.2	35.8	38.2	35.6	30.3	32.2	32.3	30.8	29.7	26.0	27.9	32.1	1.06	1.11	1.18	1.16	28.0	23.4	23.6	27.7
4	32.9	36.4	38.7	34.8	30.4	31.7	32.8	30.5	26.1	28.9	28.6	36.1	1.08	1.15	1.18	1.14	24.2	25.1	24.2	31.7
5	32.9	35.9	39.4	34.1	29.7	31.5	32.3	29.5	26.0	21.3	28.3	36.0	1.11	1.14	1.22	1.16	23.4	18.7	23.2	31.0
6	31.9	36.0	38.5	33.8	29.7	31.8	32.9	30.0	26.1	26.5	26.6	36.1	1.07	1.13	1.17	1.13	24.4	23.4	22.7	31.9
7	32.6	36.8	38.2	33.1	30.2	32.5	32.7	29.5	27.7	26.1	27.4	30.4	1.08	1.13	1.17	1.12	25.6	23.1	23.4	27.1
8	32.7	36.8	39.9	35.7	30.2	31.7	32.9	30.3	28.1	25.0	23.8	34.3	1.08	1.16	1.21	1.18	26.0	21.5	19.7	29.1
9 [5]	------	40.5	39.1	33.9	------	33.0	32.3	29.4	------	18.3	23.2	33.2	------	1.23	1.21	1.15	------	14.9	19.2	28.9
Average [6]	32.7	36.4	38.8	34.8	30.2	31.9	32.6	30.1	27.1	25.5	26.3	34.0	1.08	1.14	1.19	1.16	25.0	22.3	22.1	29.4
Standard deviation	.5	.4	.5	1.0	.3	.3	.3	.4	.4	2.0	2.0	1.9	.02	.02	.02	.02	1.4	1.8	1.8	1.7
Coefficient of variability	1.5	1.2	1.4	2.7	1.0	1.0	.9	1.5	1.5	8.0	7.7	5.7	1.4	1.4	1.5	1.9	5.5	8.2	8.2	5.9

[1] Mechanical analyses by H. W. Lakin and T. M. Shaw.
[2] Profile sample.
[3] Short plot.
[4] Long plot.
[5] Desurfaced plot.
[6] Average does not include profile sample or desurfaced plot.

TABLE 12.—*Analyses of plot composite samples, by horizons, from Nacogdoches fine sandy loam* [1]

Plot no.	Sand in horizon—					Silt in horizon—					Clay in horizon—					Colloid <0.002 mm in horizon—					Organic matter by H_2O_2 in horizon—				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
P [2]	69.7	45.7	55.1	64.8	60.3	9.8	4.9	5.9	0.8	5.6	18.0	48.4	38.9	34.3	34.0	16.1	47.1	38.2	31.7	32.7	2.2	0.7	0.0	0.0	0.0
3 [3]	69.9	48.1	53.5	----	----	10.1	5.5	5.9	----	----	18.0	45.9	40.3	----	----	17.2	45.8	38.8	----	----	1.5	.3	.0	----	----
2	69.7	45.0	54.8	----	----	8.7	5.0	5.2	----	----	19.3	49.2	39.6	----	----	16.8	46.8	33.9	----	----	1.8	.5	.0	----	----
3	69.2	48.3	57.3	----	----	10.3	5.3	4.5	----	----	18.0	45.6	37.9	----	----	15.1	43.2	35.8	----	----	2.1	.4	.0	----	----
4 [4]	----	49.0	54.6	----	----	----	5.0	4.9	----	----	----	45.2	40.0	----	----	----	44.0	38.6	----	----	----	.2	.0	----	----
Average [5]	69.6	47.1	55.2	----	----	9.7	5.3	5.2	----	----	18.4	46.9	39.3	----	----	16.4	45.3	36.2	----	----	1.8	.4	.0	----	----
Standard deviation	.3	1.5	1.6	----	----	.7	.2	.6	----	----	.6	1.6	1.0	----	----	.9	1.5	2.0	----	----	.2	.1	.0	----	----
Coefficient of variability	.4	3.2	2.9	----	----	7.4	3.9	11.0	----	----	3.4	3.5	2.6	----	----	5.6	3.3	5.6	----	----	13.6	20.9	.0	----	----

Plot no.	Colloid by water-vapor absorption in horizon—					Moisture equivalent in horizon—					Dispersion ratio in horizon—					Ratio of colloid to moisture equivalent in horizon—					Erosion ratio in horizon—				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*																
P [2]	18.6	50.5	52.5	32.9	45.2	14.3	25.2	25.1	18.6	22.5	28.2	13.8	16.0	11.5	12.4	1.30	2.00	2.10	1.77	2.01	21.7	6.9	7.6	6.5	6.2
1 [3]	20.8	50.9	48.6	----	----	14.2	25.2	25.0	----	----	23.8	18.4	12.8	----	----	1.46	2.02	1.94	----	----	16.3	9.1	6.6	----	----
2	21.5	52.1	47.9	----	----	15.1	26.8	25.3	----	----	24.9	22.3	15.6	----	----	1.42	1.95	1.89	----	----	17.5	11.4	8.3	----	----
3	19.9	49.0	45.9	----	----	15.7	25.5	24.4	----	----	27.4	19.3	16.2	----	----	1.27	1.92	1.88	----	----	21.6	10.1	8.6	----	----
4 [4]	----	51.2	48.3	----	----	----	25.9	24.9	----	----	----	17.1	13.7	----	----	----	1.98	1.94	----	----	----	8.6	7.1	----	----
Average [5]	20.7	50.7	47.5	----	----	15.0	25.8	24.9	----	----	25.4	20.0	14.9	----	----	1.38	1.96	1.90	----	----	18.5	10.2	7.8	----	----
Standard deviation	.7	1.3	1.1	----	----	.6	.7	.4	----	----	1.5	1.7	1.5	----	----	.08	.04	.03	----	----	2.3	.9	.9	----	----
Coefficient of variability	3.2	2.5	2.4	----	----	4.1	2.7	1.5	----	----	5.9	8.3	10.0	----	----	5.9	2.2	1.4	----	----	12.3	9.3	11.3	----	----

[1] Mechanical analyses by H. W. Lakin and T. M. Shaw.
[2] Profile sample.
[3] Short plot.
[4] Desurfaced plot.
[5] Average does not include profile sample or desurfaced plot.

TABLE 13.—*Analyses of plot composite samples, by horizons, from Clinton silt loam* [1]

Plot no.	Sand in horizon—					Silt in horizon—					Clay in horizon—					Colloid <0.002 mm in horizon—					Organic matter by H_2O_2 in horizon—				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
P [2]	6.0	6.6	7.0	10.7	68.6	72.7	68.5	65.8	66.5	7.6	19.1	24.3	27.0	22.4	23.2	11.2	18.8	21.8	18.2	21.4	1.7	0.1	0.0	0.0	0.0
1 [3]	4.9	4.2	8.7	24.8		75.4	69.8	64.0	48.6		17.6	25.3	26.5	26.1		12.0	20.9	21.8	24.8		1.7	.4	.5	.3	
2 [4]	5.3	5.8	8.3	15.5		75.0	69.3	63.8	59.8		17.6	23.8	27.4	24.3		10.9	20.0	22.9	19.8		1.8	.6	.2	.2	
3	4.9	5.9	8.0	19.7		80.6	69.4	64.8	55.6		12.5	24.3	26.8	24.3		11.8	18.5	22.7	20.1		1.7	.4	.3	.0	
4	5.3	4.6	6.0	11.0		74.8	69.6	66.9	63.9		18.2	25.5	26.7	24.6		11.3	19.5	22.2	22.2		1.3	.1	.2	.1	
5	4.7	5.1	5.3	7.2		77.3	71.2	68.2	68.5		16.1	22.7	25.8	23.7		11.9	18.0	22.4	21.9		1.6	.7	.6	.3	
6	4.8	5.4	5.7	7.5		77.2	71.5	68.7	68.6		16.2	22.6	25.3	23.5		10.7	18.1	22.0	21.4		1.6	.3	.1	.1	
7	5.4	4.1	5.4	7.2		77.0	72.1	69.0	69.0		15.8	23.2	25.4	23.5		11.1	18.4	22.1	21.7		1.5	.3	.1	.1	
8	5.0	4.8	6.0	6.6		76.3	72.1	68.0	69.5		16.8	22.2	25.4	23.5		12.8	18.2	23.1	20.8		1.4	.6	.4	.3	
9	5.7	5.2	6.4	6.6		74.8	69.8	66.1	67.7		17.6	24.5	27.1	25.4		12.6	19.9	23.2	20.4		1.5	.3	.1	.2	
10	5.1	5.5	5.7	7.3		75.2	71.8	66.6	66.0		17.5	21.8	27.2	26.2		13.4	17.3	23.0	22.9		1.9	.5	.2	.1	
11 [5]		5.3	6.6	8.0			71.5	67.0	67.3			22.3	25.9	23.3			18.9	23.3	20.7			.5	.0	.0	
Average [6]	5.1	5.1	6.6	11.3		76.4	70.7	66.6	63.7		16.6	23.6	26.4	24.5		11.9	18.9	22.5	21.6		1.6	.4	.3	.2	
Standard deviation	.3	.6	1.2	6.2		1.7	1.1	1.8	6.4		1.6	1.2	.8	1.0		.8	1.0	.5	1.4		.2	.2	.2	.1	
Coefficient of variability	5.8	11.7	18.4	54.4		2.2	1.6	2.7	10.0		9.4	5.2	2.9	4.1		7.0	5.5	2.1	6.5		10.8	69.2	51.0	52.4	

Plot no.	Colloid by water-vapor absorption in horizon—					Moisture equivalent in horizon—					Dispersion ratio in horizon—					Ratio of colloid to moisture equivalent in horizon					Erosion ratio in horizon—				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*																
P [2]	13.7	20.3	24.7	21.1	19.8	23.9	23.5	24.7	22.4	13.8	32.9	26.7	35.5	39.2	34.8	0.57	0.86	1.00	0.94	1.43	57.4	31.0	35.5	41.7	24.3
1 [3]	14.1	21.4	24.6	26.5		21.6	23.5	24.1	22.4		39.0	31.6	32.5	34.0		.65	.91	1.02	1.18		60.0	34.7	31.8	28.8	
2 [4]	13.3	20.5	24.9	23.0		21.6	23.5	24.4	22.7		37.0	30.8	31.2	34.1		.62	.87	1.02	1.01		59.7	35.4	30.6	33.8	
3	13.9	21.4	25.6	24.1		22.0	23.8	24.7	22.3		34.4	31.8	34.8	40.6		.63	.90	1.04	1.08		54.6	35.3	33.5	37.6	
4	14.3	21.6	25.8	25.3		22.0	24.6	25.4	23.7		31.1	32.2	35.1	42.9		.65	.88	1.02	1.07		47.8	36.6	34.4	40.1	
5	14.4	20.2	25.5	24.8		22.0	23.4	25.0	24.3		30.5	28.5	30.4	36.6		.65	.86	1.02	1.02		46.9	33.1	29.8	35.9	
6	14.1	20.5	24.8	23.8		21.4	23.9	25.3	24.3		29.5	30.7	36.5	42.8		.66	.86	.98	.98		44.7	35.7	37.2	43.2	
7	13.4	20.3	25.3	26.0		21.8	23.4	24.3	24.3		31.0	29.0	30.3	41.0		.61	.87	1.04	1.07		50.8	33.3	29.1	38.3	
8	13.5	19.1	25.0	24.0		21.7	23.3	24.9	24.2		31.6	26.4	33.6	40.6		.62	.82	1.00	.99		51.0	32.2	33.6	41.0	
9	14.4	22.1	26.2	24.7		21.5	24.3	25.6	24.1		32.0	32.7	39.2	46.3		.67	.91	1.02	1.03		47.7	35.9	38.4	44.9	
10	15.2	19.1	25.4	24.6		21.8	23.3	24.0	24.4		30.8	35.1	33.9	35.1		.70	.82	1.06	1.01		44.0	42.8	31.9	34.7	
11 [5]		19.4	26.0	23.6			23.3	25.6	23.9			34.5	40.5	47.0			.83	1.02	.99			41.6	39.7	47.5	
Average [6]	14.1	20.6	25.3	24.7		21.7	23.7	24.8	23.7		32.7	30.9	33.8	39.4		.65	.87	1.02	1.04		50.7	35.5	33.0	37.8	
Standard deviation	.5	1.0	.5	1.0		.2	.4	.5	.8		2.9	2.3	2.7	3.9		.03	.03	.02	.06		5.4	2.8	2.9	4.5	
Coefficient of variability	3.9	4.7	1.9	4.0		1.0	1.8	2.2	3.4		9.0	7.5	7.9	9.9		4.0	3.5	2.1	5.4		10.7	7.8	8.7	12.0	

[1] Mechanical analyses by H. W. Lakin and T. M. Shaw.
[2] Profile sample.
[3] Short plot.
[4] Long plot.
[5] Desurfaced plot.
[6] Average does not include profile sample or desurfaced plot.

These data indicate that the plot samples of these four soils, like those of the six previously studied, are characterized by a high degree of uniformity. The differences in many cases are probably well within the experimental error. The only case where any distinct lack of uniformity is shown is in the fourth horizon of the Clinton. The first four plots contain much more sand in this horizon than do the rest. These differences are also reflected in the silt, clay, and colloid content, but not to as great an extent. Differences appear also in the other soil properties. It would appear that the soil depth is less in the lower numbered plots than is the case with the remainder of the plots.

The plot samples compare very satisfactorily with the original profile samples in all cases, particularly with respect to the colloid, moisture equivalent, and mechanical analyses. The dispersion and erosion ratios are quite similar in the Nacogdoches and Clinton but are at a greater variance in the Palouse and Marshall, particularly in the second horizon of the Marshall. Since the plots are very uniform in respect to these determinations, the only way the writers are able to account for these differences is by assuming that there was a structural difference between the profile samples and the plot samples, or at least a structural difference caused by seasonal variation in the times of sampling.

The surface of the desurfaced plots (listed in the tables as the second horizon) agrees very well with the corresponding horizon of the normal plots in all cases except plot 15 of the Palouse. This plot, while classed as a desurfaced plot, is unlike any other plot at any of the stations, in that it was desurfaced and then refilled with clay from a nearby outcrop. The normal desurfaced plot (plot 14) was found to give unsatisfactory results, owing to the accumulation of snow during the winter in the place from which the surface soil had been removed.

The coefficients of variability are, in general, very low. The notable exceptions are in the fourth horizons of the Marshall and Clinton. In both of these cases the largest coefficient of variability is in the percentage of sand.[3]

In order better to compare the uniformity of these soils the coefficients of variability have been averaged for each horizon of each soil, and are shown in table 14.

TABLE 14.—*Average* [1] *coefficients of variability of composite plot samples*

Horizon	Palouse silt loam	Marshall silt loam	Clinton silt loam	Nacogdoches fine sandy loam
1	5.9	3.2	5.9	5.4
2	6.4	3.9	5.5	4.3
3	5.4	4.7	5.4	5.4
4	5.0	9.4	12.2	.....
Average	5.7	5.3	7.2	5.0

[1] Coefficients of variability for organic matter are not included.

[3] In all cases the standard deviation of the organic matter is relatively very low, but owing to the very low percentage of organic matter, especially in the lower horizons, the coefficient of variability is high and, in this and the following discussion (table 14), has not been considered.

The Nacogdoches has the lowest average coefficient of variability for these four soils and also for the entire series (*16, p. 42*). However, the Nacogdoches has the smallest number of plots (four), and consequently represents a smaller area. The Marshall is next in uniformity to the Nacogdoches, and just above the Colby (5.2) in the previous series. The surface horizon of the Marshall has the minimum coefficient of variability for any horizon of the whole series. In the previous series the lowest coefficient of variability was given by the second horizon of the Houston which was 4.7. In this series this figure is equaled or exceeded by the first three horizons of the Marshall and the second horizon of the Nacogdoches. With the exception of the fourth horizon of the Clinton and the Marshall, as previously mentioned, all four of these soils show an exceptionally high degree of uniformity.

RUN-OFF AND EROSION DATA

The erosion-station plots were established for the purpose of studying the effect of water in producing erosion under different conditions of cover and cultivation. The laboratory investigations in connection with these plots were organized primarily to discover whether, as erosion proceeded, marked changes are produced in the character of the residual soils. For future comparison the profile composite samples were collected and the fundamental physical properties determined and placed on record ((*16, pp. 36–41*), and tables 10–13 in this bulletin). The annual composites from each plot are taken to a uniform depth of 7 inches and subjected to a like examination. If material alteration of the soil surface is effected as a result of erosion, the results of the analyses, when compared with the original profile composite analyses, should reveal the extent and character of the changes. Such comparisons, as well as those made with the corresponding data on the material removed under various cover and other conditions, ought to give information concerning the modes of prevention of erosion. It is not to be expected that marked changes would appear within a period of a few years only, but the course of operations may be followed by annual examination. It is also possible, by such laboratory examinations, to establish comparisons between the soils at the different stations. The station first established is at Guthrie, Okla., and began operations in 1929. The station most recently established is near Zanesville, Ohio, and began operations in 1933. Sufficient time has not elapsed to give adequate data for final conclusions.

Run-off and erosion data are now available for one or more years from 7 of these stations and for 8 of the soils. No data are yet available from the Pullman, La Crosse, and Zanesville stations. The samples submitted by the stations of the dissolved solids obtained by evaporation of the run-off water have been so small and so contaminated by colloids that no analyses have been made. The annual composites (p. 2) have been examined by the same methods employed for the profile composites. The solid material removed by erosion from each plot, the wash-off samples, have also been examined in exactly the same manner. The results of these examinations are brought together with the data for the profile composite samples in tables 15 to 22, inclusive. In order to make clearer the significance of the data presented in these tables it should be mentioned that at

each station the plots are subjected to a cropping system such that some plots are subject to severe erosion each year. Other plots are protected, so far as possible, from erosion. Some are subjected to rotations, so that the amount of erosion varies from year to year. In addition, one or more plots are desurfaced in order to expose the B horizon to erosion. In addition to these variations, the fertilizer practice is different at the several stations.

It should also be noted that the wash-off samples have been collected at different times during the year and have been repeatedly oven-dried and rewet. This entails considerable segregation of material and aggregation of the colloid fraction. This segregation may readily be observed by inspection of the samples. It might have been anticipated that the wash-off material would be readily dispersed. As a matter of fact, the treatment to which it has been subjected leaves it readily dispersed but the original structure of the soil is completely destroyed. This fact makes the comparative value of the dispersion ratio doubtful, and, in consequence, the erosion ratio has not the same significance as it has in the uneroded soil.

TABLE 15.—*Analyses of annual composite samples and wash-off of Vernon fine sandy loam at Guthrie, Okla.; and related data* [1]

[Total rainfall 33.66 inches in 1930; 29.2 inches in 1931; 37.4 inches in 1932; slope 7.7 percent]

Plot no.	Sample	Colloid by water-vapor absorption	Moisture equivalent	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Sand	Silt	Clay	Colloid <0.002 mm	Organic matter by H_2O_2	Erosion	Run-off	Erosion per inch of run-off	Crop treatment
		Percent	*Percent*				*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Tons per acre*	*Percent*	*Tons per acre*	
1 [3]	Profile composite	5.2	7.1	41.8	0.73	57.3	76.0	16.0	7.0	5.6	0.7				
	1930 wash-off [2]	5.5	10.2	59.2	.54	109.6	72.7	18.5	7.1	5.7	.4	21.26	11.55	5.5	Cotton.
	1931 composite	5.2	7.7	25.6	.68	37.7	75.2	16.7	7.0	6.5	.8				
	1931 wash-off	8.1	15.2	68.3	.53	129.0	61.1	23.1	13.2	11.7	1.7	7.93	10.37	2.2	Do.
	1932 composite	5.7	7.0	39.4	.81	48.6	75.3	16.9	6.6	5.9	.8				
	1932 wash-off	4.2	5.3	55.5	.79	70.2	79.1	14.9	5.0	3.7	.9	47.93	19.33	9.3	Do.
2	Profile composite	7.0	9.5	33.0	.74	44.6	72.9	17.0	9.0	6.7	.9				
	1930 wash-off	7.6	13.7	68.2	.55	124.0	65.4	24.0	8.5	7.7	1.6	14.49	10.04	4.3	Do.
	1931 composite	6.8	9.8	24.0	.69	34.8	72.7	17.5	8.4	7.2	1.3				
	1931 wash-off	6.8	10.8	60.8	.63	96.5	69.8	20.0	8.7	6.9	1.3	25.51	13.48	5.5	Do
	1932 composite	6.6	8.7	36.8	.76	48.5	72.9	17.5	8.1	7.2	1.0				
	1932 wash-off	5.8	8.5	56.3	.68	82.7	75.3	16.7	6.9	4.7	.9	88.04	15.43	21.3	Do.
3	Profile composite	6.4	9.3	32.3	.69	46.8	73.1	17.0	8.5	6.7	1.0				
	1930 wash-off	6.1	11.8	54.8	.52	105.4	66.4	20.9	10.6	7.6	.7	17.56	13.11	4.0	Do.
	1931 composite	6.7	9.3	26.5	.72	39.6	72.8	18.2	7.7	6.8	1.1				
	1931 wash-off	6.7	10.5	60.4	.64	94.4	67.1	22.1	8.9	7.2	1.5	11.57	13.21	2.6	Do.
	1932 composite	5.6	8.1	40.0	.69	57.9	74.3	17.1	7.5	6.7	.9				
	1932 wash-off	5.1	6.2	54.4	.82	66.3	74.7	17.3	6.8	5.0	.9	68.52	14.70	17.4	Do.
4	Profile composite	7.6	9.4	32.7	.81	40.3	72.9	16.1	9.8	7.6	1.0				
	1930 wash-off	14.5	22.6	77.8	.64	121.5	45.4	31.5	19.0	15.0	3.5	3.09	13.36	.69	Wheat (oats).
	1931 composite	6.9	9.4	25.1	.73	34.4	72.6	18.1	8.0	6.5	1.1				
	1931 wash-off	25.0	32.3	57.8	.77	75.1	26.6	43.1	22.8	17.8	6.9	.98	10.59	.27	Sweetclover.
	1932 composite	6.6	8.6	38.4	.77	49.9	72.8	17.7	8.2	6.7	1.0				
	1932 wash-off	9.8	14.0	53.8	.70	76.9	59.9	27.3	11.0	8.7	1.5	39.31	12.46	11.8	Cotton.
5	Profile composite	6.4	9.8	40.7	.65	62.6	74.0	15.8	8.8	6.6	1.1				
	1930 wash-off	16.8	29.5		.57		38.5	37.5	18.8	12.0	5.8	.51	9.76	.16	Sweetclover.
	1931 composite	7.8	9.2	27.3	.85	32.1	72.5	18.3	8.1	6.2	.5				
	1931 wash-off	14.0	19.4	61.0	.72	84.7	50.1	31.1	15.6	13.3	2.7	5.89	10.36	1.7	Cotton.
	1932 composite	7.6	9.6	38.5	.79	48.7	71.8	17.6	9.1	6.6	1.2				
	1932 wash-off	18.3	24.1	51.4	.76	67.7	46.3	28.0	21.6	15.7	3.4	.98	11.00	.33	Wheat.
6	Profile composite	7.4	10.1	36.1	.73	49.4	71.8	16.8	10.0	8.1	1.2				
	1930 wash-off	8.1	12.5	60.2	.65	92.6	72.0	16.2	9.8	8.1	.5	13.32	11.95	3.3	Cotton.
	1931 composite	8.1	9.4	23.6	.86	27.4	71.7	17.9	9.2	7.9	.9				
	1931 wash-off	31.2	42.0	60.1	.74	81.2	14.8	42.9	34.4	23.4	7.3	.52	10.96	.14	Wheat.
	1932 composite	7.2	9.3	39.4	.77	50.9	73.6	16.1	9.1	7.6	.8				
	1932 wash-off	35.2	43.3	63.3	.81	78.1	15.1	38.9	36.3	26.7	8.5	.56	9.00	.23	Sweetclover.

7	Profile composite	7.3	10.5	33.5	.70	47.9	71.5	17.1	9.9	7.9	1.4			
	1930 wash-off	7.5	11.8		.64		70.7	17.1	9.9	6.6		.06	2.83	.06	Bermuda grass.
	1931 composite	9.0	11.1	28.9	.81	35.7	71.7	17.6	9.5	8.4	1.2			
	1931 wash-off	14.3	23.6	57.5	.61	94.2	62.0	19.8	13.9	10.6	2.9	.01	.47	.06	Do.
	1932 composite	7.7	10.3	34.1	.75	45.6	72.8	16.5	8.9	7.1	1.4			
	1932 wash-off	21.4	31.2	56.2	.69	81.4	42.0	36.2	16.8	10.4	4.1	.03	1.69	.07	Do.
8	Profile composite	7.2	10.5	31.3	.69	45.4	70.5	19.2	9.1	7.5	1.0			
	1930 wash-off	7.5	9.8	52.6	.76	69.2	72.1	16.7	9.3	7.1	.8	18.09	22.95	2.3	Bare.
	1931 composite	8.5	9.1	32.2	.93	34.6	71.9	16.5	10.3	7.9	.9				
	1931 wash-off	11.4	15.6	49.8	.73	68.2	61.3	24.2	12.1	10.1	1.9	6.33	21.52	.86	Do.
	1932 composite	6.2	8.7	36.0	.71	50.5	73.2	16.8	8.8	7.6	.7				
	1932 wash-off	9.0	10.8	49.5	.83	59.6	70.6	17.6	10.2	8.0	1.1	13.85	27.34	1.9	Do.
9 [5]	Profile composite	13.4	13.3	23.1	1.01	22.9	65.8	14.9	18.6	16.2	.5				
	1930 wash-off	13.7	13.4	42.6	1.02	41.8	57.9	18.7	22.9	19.9	.5	35.25	26.39	4.0	Cotton.
	1931 composite	16.1	14.7	33.7	1.10	30.6	62.1	17.7	19.4	17.7	.4				
	1931 wash-off	19.5	22.1	57.5	.88	65.3	44.8	24.0	30.1	24.9	.7	13.69	23.65	1.7	Do.
	1932 composite	12.6	13.5	31.6	.93	29.5	69.7	14.9	14.7	13.1	.4				
	1932 wash-off	17.9	17.2	55.8	1.04	53.6	52.5	21.5	24.0	20.3	1.7	51.95	31.73	6.1	Do.
Average [6]	Profile composite	6.8	9.5	35.2	.72	49.3	72.8	16.9	9.0	7.1	1.0				
	1930 wash-off	9.2	15.2	62.1	.61	103.7	62.9	22.8	11.6	8.7	1.9	11.05	11.94	2.54	
	1931 composite	7.4	9.4	26.9	.78	34.5	72.6	17.6	8.5	7.2	1.0				
	1931 wash-off	14.7	21.2	59.5	.67	90.4	51.6	28.3	16.2	12.6	3.3	7.34	11.23	1.67	
	1932 composite	6.7	8.8	37.8	.76	50.1	73.3	17.0	8.3	6.9	1.0				
	1932 wash-off	13.6	17.9	55.1	.76	72.9	57.9	24.6	14.3	10.4	2.7	32.40	13.87	7.79	

[1] Mechanical analyses by H. W. Lakin and T. M. Shaw.
[2] No composite samples were taken in 1930.
[3] Short plot.
[4] Long plot.
[5] Desurfaced plot.
[6] Average does not include desurfaced plot.

NOTE.—Profile composite samples were taken to a depth of 5 inches.

TABLE 16.—*Analyses of annual composite samples and wash-off of Kirvin fine sandy loam at Tyler, Tex.; and related data*[1]

[Total rainfall 36.1 inches in 1931; 46.71 inches in 1932; 8.75 percent slope]

Plot no.	Sample	Colloid by water-vapor absorption	Moisture equivalent	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Sand	Silt	Clay	Colloid <0.002 mm	Organic matter by H_2O_2	Erosion	Run-off	Erosion per inch of run-off	Crop treatment
		Percent	*Percent*				*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Tons per acre*	*Percent*	*Tons per acre*	
	Profile composite	5.1	7.8	28.8	0.65	44.3	77.5	14.3	7.4	5.9	0.5				
	1931 composite	6.8	8.3	41.7	.82	50.8	79.3	13.0	6.7	4.9	.6				
1[2]	1931 wash-off	6.9	10.0	58.9	.69	85.3	75.7	17.4	4.9	3.6	1.6	9.93	12.0	2.29	Cotton.
	1932 composite	6.0	7.0	37.7	.86	43.8	77.9	13.2	7.8	5.8	.8				
	1932 wash-off	6.6	10.0	64.1	.66	97.8	73.2	10.7	14.2	8.3	1.6	12.36	19.1	1.39	Do.
	Profile composite	6.7	8.5	31.2	.79	39.5	76.3	13.8	9.4	7.2	.4				
	1931 composite	6.1	8.3	33.8	.74	45.7	78.1	14.3	6.7	5.4	.5				
2[3]	1931 wash-off	6.2	9.8	61.9	.63	98.3	73.5	19.0	6.1	3.7	1.0	21.89	13.6	4.46	Do.
	1932 composite	6.2	7.1	32.4	.87	37.2	75.8	14.6	8.6	7.3	.7				
	1932 wash-off	5.0	6.1	76.4	.82	93.2	78.4	13.3	7.6	5.5	.6	44.26	21.8	4.35	Do.
	Profile composite	6.7	8.4	33.6	.80	42.0	76.1	15.4	7.7	5.5	.4				
	1931 composite	5.5	8.1	27.0	.68	39.7	78.1	14.3	6.7	4.8	.7				
3	1931 wash-off	6.7	10.1	57.5	.66	87.1	72.5	17.6	8.6	4.7	.8	17.24	13.2	3.61	Do.
	1932 composite	6.0	7.3	38.4	.82	46.8	76.9	14.7	7.7	6.1	.5				
	1932 wash-off	6.7	9.6	49.7	.70	71.0	73.6	16.2	9.0	6.6	1.0	17.48	25.0	1.50	Do.
	Profile composite	6.1	7.9	33.3	.77	43.3	76.2	15.2	7.8	5.9	.4				
	1931 composite	5.5	8.5	42.2	.65	64.9	77.7	14.8	6.6	5.0	.6				
4	1931 wash-off	7.0	10.6	59.0	.66	89.4	72.0	17.5	9.2	5.8	1.0	14.47	13.6	2.95	Cotton (fertilized).
	1932 composite	7.2	7.5	44.4	.96	35.8	77.4	13.6	8.1	6.5	.6				
	1932 wash-off	5.7	8.0	64.6	.71	91.0	76.6	13.6	8.5	6.8	.9	19.23	25.3	1.63	Cotton.
	Profile composite	6.0	8.0	25.3	.75	33.7	76.0	14.7	8.5	7.2	.7				
	1931 composite	6.1	8.4	40.6	.73	55.6	78.4	14.5	6.3	5.2	.7				
5	1931 wash-off	6.8	10.5	57.2	.65	88.0	74.0	15.4	9.0	5.2	1.0	16.59	12.0	3.83	Cotton (cover crop).
	1932 composite	5.6	7.3	38.6	.77	50.1	78.3	13.3	7.6	6.3	.5				
	1932 wash-off	5.4	8.9	62.9	.61	103.2	75.7	14.2	8.6	6.4	1.2	17.87	23.8	1.61	Corn (cover crop).
	Profile composite	3.1	8.2	29.7	.74	40.0	76.8	13.8	8.7	6.4	.6				
	1931 composite	5.9	7.9	32.9	.75	43.9	78.8	11.8	8.4	7.0	.5				
6	1931 wash-off	6.5	10.3	61.8	.63	98.1	75.0	15.3	8.6	5.2	.7	20.72	16.6	3.46	Do.
	1932 composite	5.8	7.5	36.1	.77	46.9	79.0	12.4	7.7	6.7	.8				
	1932 wash-off	6.2	8.9	60.8	.70	86.8	74.2	14.3	9.4	6.7	1.8	11.64	26.5	.94	Lespedeza (cover crop).
	Profile composite	6.3	8.3	27.3	.76	35.9	78.3	12.0	8.4	6.6	1.0				
	1931 composite	5.8	8.5	32.3	.68	47.5	78.3	12.2	8.5	7.5	.5				
7	1931 wash-off	11.1	17.4	59.3	.64	92.7	59.3	24.4	13.2	8.8	2.9	3.46	9.4	1.02	Do.
	1932 composite	6.3	7.3	35.4	.86	41.2	78.8	13.2	7.0	5.6	.8				
	1932 wash-off	6.4	9.4	57.6	.68	84.7	74.8	14.7	9.0	6.6	1.1	18.11	18.7	.97	Cotton (cover crop).

8	Profile composite	6.7	8.7	22.0	.77	28.6	76.8	12.5	9.6	7.0	.8			
	1931 composite	5.8	9.3	36.8	.62	59.4	78.4	12.0	8.5	7.8	.6			
	1931 wash-off	13.9	21.5	61.0	.65	93.8	61.3	19.3	12.8	11.5	5.1	.49	2.6	.52 Bermuda sod.
	1932 composite	6.6	8.2	35.4	.80	44.3	78.8	12.9	7.1	5.0	1.0			
	1932 wash-off	3.2	6.4	53.8	.50	107.6	84.8	6.3	7.0	4.7	.9	.09	1.9	.11 Do.
9	Profile composite	7.5	8.6	27.5	.87	31.6	79.2	10.7	9.3	7.6	.8			
	1931 composite	6.6	8.4	39.2	.79	49.6	78.3	11.1	9.7	8.0	.5			
	1931 wash-off	7.4	9.3	53.3	.80	66.6	76.5	13.9	8.0	5.5	1.4	14.90	13.7	3.02 Bare (hard fallow).
	1932 composite	8.0	7.5	24.9	1.07	23.3	80.4	12.3	6.4	5.3	.6			
	1932 wash-off	7.9	9.8	63.1	.81	77.9	76.0	12.7	9.4	6.8	1.6	13.15	23.2	1.21 Do.
10 [4]	Profile composite	61.2	35.3	14.8	1.73	8.6	24.9	6.3	67.9	65.6	.6			
	1931 composite	62.0	35.4	14.2	1.75	8.1	25.2	7.5	66.4	64.9	.4			
	1931 wash-off	54.4	28.5	16.4	1.91	8.6	27.3	9.2	63.0	60.1	.3	46.50	17.6	7.32 Cotton (fertilized; cover crop).
11 [4]	1932 composite	69.5	38.5	9.2	1.80	5.1	20.3	9.2	69.8	68.0	.4			
	1932 wash-off	60.5	30.0	13.0	2.02	6.4	18.7	6.3	73.8	71.9	.7	56.33	33.6	3.59 Do.
	Profile composite	62.3	35.0	15.2	1.78	8.5	24.2	7.2	67.9	65.0	.5			
	1931 composite	65.5	36.4	15.9	1.80	8.8	22.4	7.3	69.2	68.0	.6			
	1931 wash-off	55.8	29.2	13.3	1.91	7.0	26.4	7.8	65.2	63.6	.2	58.02	16.8	9.57 Cotton (fertilized).
12 [4]	1932 composite	63.7	35.6	8.9	1.79	5.0	26.4	9.2	63.4	63.0	.7			
	1932 wash-off	59.2	31.1	14.5	1.90	7.6	19.6	6.2	73.1	70.0	.4	67.45	27.2	5.30 Do.
	Profile composite	57.4	32.9	14.9	1.74	8.6	28.9	7.8	62.4	59.7	.7			
	1931 composite	52.7	31.4	14.7	1.68	8.7	33.7	8.0	57.4	52.6	.4			
	1931 wash-off	47.7	26.2	14.3	1.82	7.9	32.5	9.3	57.3	55.6	.0	60.23	18.4	9.07 Cotton.
	1932 composite	63.6	35.4	10.1	1.80	5.6	31.4	9.4	57.7	57.4	1.1			
	1932 wash-off	53.7	28.3	15.2	1.90	8.0	27.7	6.6	64.2	61.4	.8	73.66	27.6	5.71 Do.
Average [5]	Profile composite	6.4	8.3	28.7	.77	37.7	77.0	13.6	8.5	6.6	.6			
	1931 composite	6.0	8.4	34.3	.72	50.8	78.4	13.1	7.6	6.2	.6			
	1931 wash-off	8.1	12.2	58.9	.67	88.8	71.1	17.8	7.9	6.0	1.7	13.30	11.9	2.80
	1932 composite	6.4	7.4	34.8	.86	41.0	78.1	13.4	7.6	6.1	.7			
	1932 wash-off	5.9	8.6	61.4	.69	90.4	76.4	12.9	9.2	6.5	1.2	17.13	20.6	1.52

[1] Determinations bases by H. W. Lakin and T. M. Shaw.
[2] Short plot.
[3] Long plot.
[4] Desurfaced plot
[5] Average does not include desurfaced plots.

NOTE.—Profile composite samples were taken to a depth of 10 to 12 inches, except desurfaced plots, which were sampled to a depth of 7 inches.

TABLE 17.—*Analyses of annual composite samples and wash-off of Colby silty clay loam, Hays, Kans.; and related data* [1]

[Total rainfall 21.39 inches in 1931; 29.63 inches in 1932; slope 5 percent]

Plot no.	Sample	Colloid by water-vapor absorption	Moisture equivalent	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Sand	Silt	Clay	Colloid <0.002 mm	Organic matter by H_2O_2	Erosion	Runoff	Erosion per inch of runoff	Crop treatment
		Percent	*Percent*				*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Tons per acre*	*Percent*	*Tons per acre*	
1 [2]	Profile composite	29.3	25.2	22.7	1.16	19.6	17.6	47.3	33.2	28.7	1.4				
	1931 composite	29.9	27.5	25.3	1.09	23.2	15.7	49.6	32.2	27.5	1.9				
	1931 wash-off	43.7	42.9	49.2	1.02	48.2	4.1	44.2	47.4	36.6	3.4	0.36	2.96	0.57	Wheat.
	1932 composite	30.5	25.6	18.5	1.19	15.5	18.4	46.4	31.4	27.1	3.0				
	1932 wash-off	32.4	30.3	57.4	1.07	53.7	6.8	51.2	38.6	32.5	2.8	5.82	15.96	1.23	Do.
2 [3]	Profile composite	32.0	26.8	18.6	1.19	15.7	18.3	45.7	34.5	27.9	.9				
	1931 composite	30.1	27.4	26.6	1.10	24.2	15.4	50.1	31.9	27.4	2.1				
	1931 wash-off	40.3	43.5	58.6	.93	63.0	5.4	43.9	47.0	40.5	2.6	.33	4.77	.32	Do.
	1932 composite	31.0	25.8	16.6	1.20	13.8	17.1	47.0	32.2	27.0	2.8				
	1932 wash-off	35.7	35.3	71.6	1.01	70.8	4.8	48.7	43.3	36.3	2.8	5.96	11.57	1.74	Do.
3	Profile composite	30.6	27.5	19.9	1.11	17.9	15.6	47.0	34.9	27.7	1.7				
	1931 composite	30.4	27.1	24.5	1.12	21.9	16.2	48.8	32.1	27.7	2.2				
	1931 wash-off	43.8	41.7	67.5	1.05	64.3	2.2	44.7	49.2	40.0	3.0	.27	2.79	.45	Do.
	1932 composite	30.6	26.0	16.2	1.18	13.7	17.6	48.4	31.1	26.2	2.2				
	1932 wash-off	46.1	43.2	81.8	1.07	80.2	1.5	42.3	52.1	44.0	3.3	5.69	15.35	1.25	Do.
4	Profile composite	31.6	28.6	18.4	1.10	16.7	14.0	48.5	33.8	26.3	2.9				
	1931 composite	32.7	29.3	20.9	1.12	18.7	12.4	52.9	31.0	26.3	2.8				
	1931 wash-off	33.1	37.8	31.7	.88	36.0	9.6	53.1	32.9	27.1	3.9	.03	.33	.40	Native grass clipped.
	1932 composite	33.2	27.8	16.2	1.19	13.6	14.2	52.4	29.6	26.5	3.0				
	1932 wash-off	33.7	33.1	53.8	1.02	52.7	10.0	49.3	37.3	30.0	2.8	.06	.88	.23	Do.
5	Profile composite	31.9	27.8	19.5	1.15	16.8	15.4	48.4	34.3	29.5	1.5				
	1931 composite	30.0	26.8	26.6	1.12	23.7	15.5	43.9	38.0	29.0	1.8				
	1931 wash-off	30.8	30.4	50.8	1.01	50.3	10.6	50.2	36.2	30.6	2.1	20.85	11.79	8.23	Kafir.
	1932 composite	30.5	25.1	17.2	1.22	14.1	18.1	46.2	32.4	27.5	2.6				
	1932 wash-off	48.0	43.5	68.3	1.10	62.1	3.4	41.2	51.6	42.8	3.2	38.26	25.53	5.05	Fallow.
6	Profile composite	31.1	26.6	20.5	1.17	17.5	16.5	47.3	34.4	28.5	1.5				
	1931 composite	30.5	26.9	24.1	1.13	21.8	16.5	43.3	37.5	28.4	2.1				
	1931 wash-off	43.9	42.6	60.6	1.03	58.8	2.4	43.0	50.7	40.8	3.0	.65	6.27	.49	Wheat.
	1932 composite	30.5	25.7	23.0	1.19	19.3	18.0	43.8	35.0	27.7	2.6				
	1932 wash-off	43.6	42.3	65.2	1.03	63.3	9.1	44.6	43.4	36.0	2.3	23.10	25.80	3.02	Kafir.
7	Profile composite	30.1	26.5	19.0	1.14	16.7	18.2	45.1	34.5	27.1	1.7				
	1931 composite	30.7	26.7	24.2	1.15	21.0	15.2	47.8	34.2	28.4	1.9				
	1931 wash-off	34.2	32.4	51.6	1.06	48.7	8.6	49.3	39.1	34.3	2.2	8.02	6.90	5.44	Fallow.
	1932 composite	30.8	26.0	22.4	1.18	19.0	17.7	46.2	32.9	27.8	2.4				
	1932 wash-off	39.7	41.2	77.3	.96	80.5	4.4	48.3	43.9	36.0	2.7	6.50	17.20	1.28	Wheat.

8	Profile composite	30.3	26.4	18.8	1.15	16.3	16.6	47.2	33.8	26.9	1.8			
	1931 composite	30.6	26.9	27.0	1.14	23.7	15.8	48.5	33.0	27.7	1.6			
	1931 wash-off	35.2	32.8	49.9	1.07	46.6	8.8	50.1	38.5	27.7	1.6	15.30	11.09	6.45
	1932 composite	30.1	25.4	19.5	1.18	16.5	18.2	47.0	31.7	27.0	2.4			
	1932 wash-off	44.0	40.8	70.0	1.08	64.8	7.2	50.5	39.7	32.6	2.0	31.27	21.76	4.85
9	Profile composite	29.9	28.2	17.5	1.06	16.6	14.5	52.4	31.1	26.7	.8			
	1931 composite	33.2	29.3	20.5	1.13	18.1	12.6	53.9	29.9	26.4	2.9			
	1931 wash-off	38.2	40.3	52.2	1.06	49.2	5.8	52.8	36.7	32.2	3.8	.0025	.05	.23
	1932 composite	33.3	28.3	15.3	1.18	13.0	14.7	50.5	30.3	25.7	4.0			
	1932 wash-off	38.0	37.4		1.02		6.1	47.6	42.8	38.0	2.3	.0035	.02	.50
10 [4]	Profile composite	26.7	25.2	25.5	1.06	24.1	15.0	47.7	37.1	27.8	.0			
	1931 composite	29.0	24.7	23.3	1.17	19.9	11.8	50.7	36.3	29.0	.5			
	1931 wash-off	33.7	32.5	63.0	1.04	60.6	3.9	46.6	47.0	33.2	1.5	3.40	15.43	1.03
	1932 composite	26.8	22.9	18.4	1.17	15.7	16.3	48.1	34.1	26.1	1.0			
	1932 wash-off	26.0	31.0	63.2	.84	75.2	9.1	56.8	33.4	25.1	.7	37.21	28.50	4.40
Average [5]	Profile composite	30.8	27.1	19.3	1.14	17.1	16.3	47.7	33.8	27.7	1.6			
	1931 composite	30.9	27.5	24.4	1.12	21.8	15.0	48.8	33.3	27.6	2.1			
	1931 wash-off	38.1	38.3	52.5	1.02	51.7	6.4	47.9	42.0	34.4	2.8	5.09	5.22	2.51
	1932 composite	31.2	26.2	18.3	1.19	15.4	17.1	47.5	31.8	26.9	2.8			
	1932 wash-off	40.1	38.6	68.2	1.04	66.0	5.9	47.1	43.6	36.5	2.7	12.96	14.90	2.13

[1] Mechanical analyses by H. W. Lakin and T. M. Shaw.
[2] Short plot.
[3] Long plot.
[4] Desurfaced plot.
[5] Average does not include desurfaced plot.

NOTE.—Profile composite samples were taken to a depth of 10 inches, except desurfaced plot, which was sampled to a depth of 12 inches.

TABLE 18.—*Analyses of annual composite samples and wash-off of Houston black clay at Temple, Tex.; and related data* [1]

[Total rainfall in 1931, 25.17 inches; in 1932, 31.25 inches; slope 4 percent]

Plot no.	Sample	Colloid by water-vapor absorption	Moisture equivalent	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Sand	Silt	Clay	Colloid <0.002 mm	Organic matter by H_2O_2	Erosion	Run-off	Erosion per inch of run-off	Crop treatment
		Percent	*Percent*				*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Tons per acre*	*Percent*	*Tons per acre*	
1 [2]	Profile composite	38.6	29.7	12.5	1.30	9.6	11.1	23.9	62.9	44.2	1.8				
	1931 composite	42.6	31.4	14.7	1.36	10.8	9.6	24.7	63.1	45.4	1.8				
	1931 wash-off	38.3	34.3	27.5	1.12	24.6	6.7	28.0	62.6	40.1	1.9	4.9	5.7	3.4	Corn.
	1932 composite	42.3	30.2	10.9	1.40	7.8	10.8	24.2	61.8	43.3	2.4				
	1932 wash-off	39.6	31.4	31.0	1.26	24.6	8.0	25.9	63.4	45.0	2.0	19.8	13.0	4.9	Do.
2 [3]	Profile composite	36.4	29.8	12.3	1.22	10.1	9.3	27.5	62.0	44.7	.8				
	1931 composite	40.3	30.5	14.1	1.32	10.7	8.3	25.7	63.4	45.7	2.0				
	1931 wash-off	38.6	31.5	26.1	1.23	21.2	6.7	24.3	65.9	45.8	2.6	1.5	5.3	1.1	Do.
	1932 composite	39.8	28.9	9.5	1.38	6.9	8.2	24.8	63.9	43.2	2.3				
	1932 wash-off	39.4	31.3	33.9	1.26	26.9	6.4	23.7	67.6	45.7	1.9	20.6	10.5	6.3	Do.
3	Profile composite	38.6	30.8	9.7	1.25	7.8	9.5	26.6	62.2	45.4	1.2				
	1931 composite	43.0	32.6	14.0	1.32	10.6	8.4	24.9	63.9	47.5	2.2				
	1931 wash-off	40.1	35.5	34.3	1.13	30.3	3.6	22.1	71.2	47.4	2.2	2.5	5.2	1.9	Do.
	1932 composite	42.6	30.0	10.3	1.42	7.2	9.3	25.0	62.1	44.2	2.9				
	1932 wash-off	40.2	32.1	34.2	1.25	27.4	7.8	23.7	66.0	44.6	2.1	18.9	11.1	5.4	Do.
4	Profile composite	39.3	30.2	11.9	1.30	9.1	9.7	25.9	62.6	45.4	1.3				
	1931 composite	42.3	32.4	15.8	1.31	12.1	8.5	24.9	63.8	46.3	2.2				
	1931 wash-off	42.6	37.9	36.1	1.12	32.2	1.0	20.7	75.0	46.8	2.3	.8	4.2	.8	Do.
	1932 composite	43.8	31.1	9.6	1.41	6.8	8.6	25.0	62.8	44.6	2.8				
	1932 wash-off	38.8	31.2	30.3	1.24	24.4	7.5	24.8	64.6	43.6	2.2	Trace	Trace		Oats (green manure).
5	Profile composite	40.2	30.5	9.2	1.32	7.0	9.3	24.9	64.8	48.4	.8				
	1931 composite	41.7	31.6	12.9	1.32	9.8	8.6	24.4	64.2	46.2	2.1				
	1931 wash-off	43.4	33.7	35.0	1.29	27.1	5.4	24.7	66.3	43.7	2.8	.6	1.8	1.3	Corn.
	1932 composite	42.6	29.9	9.2	1.42	6.5	8.6	24.3	63.8	44.9	2.6				
	1932 wash-off	40.8	31.2	34.2	1.31	26.1	6.5	24.1	66.8	45.8	1.8	.5	.6	2.6	Oats.
6	Profile composite	39.0	31.1	11.2	1.25	9.0	10.9	25.2	63.6	45.7	1.0				
	1931 composite	42.4	33.2	15.6	1.28	12.2	8.3	24.9	63.7	46.2	2.4				
	1931 wash-off											None	None		Bermuda grass.
	1932 composite	43.7	31.3	9.8	1.40	7.0	8.6	24.4	63.4	44.6	3.0				
	1932 wash-off											None	None		Do.
7	Profile composite	39.8	29.2	9.6	1.36	7.1	9.3	25.3	64.8	46.3	.3				
	1931 composite	42.2	32.3	13.7	1.31	10.5	7.4	25.8	64.6	46.8	1.5				
	1931 wash-off	41.4	34.8	34.7	1.19	29.2	3.2	23.7	70.0	47.5	2.1	1.0	3.3	1.2	Cotton.
	1932 composite	42.5	29.6	11.3	1.44	7.8	9.5	24.9	62.2	44.0	2.7				
	1932 wash-off	40.7	32.5	35.5	1.25	28.4	6.2	24.3	67.1	45.8	2.0	19.8	10.9	5.8	Corn.

8	Profile composite	38.2	29.3	8.4	1.30	6.5	8.8	24.7	65.7	46.0	.3			
	1931 composite	41.3	31.3	12.6	1.32	9.5	7.7	25.5	64.1	46.0	2.0			
	1931 wash-off	40.0	37.5	42.8	1.07	40.0	1.0	16.9	79.2	44.7	2.1	.7	3.0	.9 Do.
	1932 composite	42.0	29.7	10.8	1.41	7.7	7.7	24.6	64.5	45.5	2.4			
	1932 wash-off	37.4	31.3	35.9	1.20	29.9	7.0	21.7	68.7	45.1	1.9	.4	.3	4.3 Oats.
9	Profile composite	39.0	30.1	13.4	1.30	10.3	9.6	25.1	64.6	45.2	.3			
	1931 composite	40.3	31.6	12.6	1.28	9.8	8.4	25.4	63.5	49.7	2.0			
	1931 wash-off	36.6	31.2	21.6	1.17	18.5	9.4	26.1	61.5	41.3	2.2	.2	1.8	.4 Oats (green manure).
	1932 composite	41.8	29.8	9.9	1.40	7.1	8.6	24.6	64.8	46.0	1.6			
	1932 wash-off	39.1	32.8	36.0	1.19	30.2	5.1	23.4	68.6	46.1	2.2	9.2	7.2	4.1 Cotton.
10	Profile composite	39.4	29.9	11.8	1.32	8.9	9.1	20.8	69.8	47.0	.0			
	1931 composite	40.6	31.4	9.2	1.29	7.1	7.7	26.0	63.8	45.7	1.8			
	1931 wash-off	37.4	33.7	37.1	1.11	33.4	5.0	23.3	68.7	41.5	2.2	.5	2.3	.9 Corn.
	1932 composite	42.3	30.4	9.0	1.39	6.5	8.1	24.4	65.4	45.7	1.6			
	1932 wash-off	37.9	32.9	31.4	1.15	27.3	5.9	22.0	69.3	48.7	2.0	Trace	Trace	Oats (green manure).
11 [4]	Profile composite	30.4	24.0	6.0	1.27	4.7	8.1	26.8	64.8	37.3	.1			
	1931 composite	30.6	25.8	10.3	1.19	8.7	8.0	26.8	64.0	41.2	.8			
	1931 wash-off	32.7	29.9	36.1	1.09	33.1	5.2	28.6	64.2	38.1	1.3	.4	2.4	.7 Corn.
	1932 composite	31.7	24.4	11.6	1.30	8.9	7.4	24.5	66.7	41.9	.8			
	1932 wash-off	31.9	26.5	26.6	1.20	22.2	9.8	23.3	65.5	40.5	.9	1.3	2.1	2.0 Oats.
Average [5]	Profile composite	38.9	30.1	11.0	1.29	8.5	9.7	25.0	64.3	45.8	.8			
	1931 composite	41.7	31.8	13.5	1.31	10.3	8.3	25.2	63.8	46.6	2.0			
	1931 wash-off	39.8	34.5	32.8	1.16	28.5	4.7	23.3	68.9	44.3	2.3	1.3	3.3	1.2 --
	1932 composite	42.3	30.1	10.0	1.41	7.1	8.8	24.6	63.5	44.9	2.4			
	1932 wash-off	39.3	31.9	33.6	1.23	27.2	6.7	23.7	66.9	45.6	2.0	8.9	5.4	3.3

[1] Mechanical analyses by H. W. Lakin and T. M. Shaw.
[2] Short plot.
[3] Long plot.
[4] Desurfaced plot.
[5] Average does not include desurfaced plots.

NOTE.—Profile composite samples taken to a depth of 10 to 12 inches, except desurfaced plots, which were sampled to a depth of 7 inches.

TABLE 19.—*Analyses of composite surface samples and wash-off of Shelby silt loam, Bethany, Mo.; with related data* [1]

[Total rainfall, 42.52 inches in 1931, 27.04 inches in 1932; slope 8 percent]

Plot no.	Sample	Colloid by water-vapor absorption	Moisture equivalent	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Sand	Silt	Clay	Colloid <0.002 mm	Organic matter by H_2O_2	Erosion	Run-off	Erosion per inch of run-off	Crop treatment
		Percent	*Percent*				*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Tons per acre*	*Percent*	*Tons per acre*	
L-1 [2]	Profile composite	24.7	24.3	25.4	1.02	24.9	23.8	45.9	26.5	22.1	3.5				
	1931 composite	24.6	25.9	37.1	.95	39.1	24.4	45.7	26.7	23.4	2.5				
	1931 wash-off	25.4	27.5	53.9	.92	58.6	16.7	51.0	28.6	23.8	3.0	105.78	28.22	8.8	Corn.
	1932 composite	24.9	24.6	20.7	1.01	20.5	25.1	44.5	27.2	23.4	2.8				
	1932 wash-off	22.8	26.2	57.8	.87	66.4	17.1	48.1	30.9	26.1	3.3	52.26	15.34	12.6	Do.
U-1 [3]	Profile composite	27.1	27.0	28.3	1.00	28.3	13.3	52.2	29.6	24.1	4.3				
	1931 composite	25.8	27.6	35.3	.93	38.0	14.2	52.6	29.2	24.6	3.4				
	1932 composite	26.5	26.5	22.2	1.00	22.2	14.2	49.5	32.2	27.8	3.8				
2	Profile composite	25.0	24.3	30.7	1.03	29.8	24.8	45.2	25.6	20.9	3.8				
	1931 composite	24.8	25.5	39.5	.97	40.7	24.9	45.3	26.5	22.2	2.5				
	1931 wash-off	25.4	27.9	57.6	.91	63.3	17.9	49.2	29.1	25.9	3.2	85.17	30.10	6.7	Do.
	1932 composite	24.3	23.9	20.4	1.02	20.0	26.6	40.9	28.8	23.5	3.1				
	1932 wash-off	24.7	27.1	52.3	.91	57.5	16.8	46.8	32.8	25.2	3.4	48.58	19.07	9.4	Do.
3	Profile composite	24.3	25.0	26.6	.97	27.4	23.8	43.9	28.9	22.9	3.3				
	1931 composite	25.2	26.4	37.2	.95	39.2	24.5	45.6	26.6	23.2	2.7				
	1931 wash-off	26.4	28.5	55.1	.93	59.2	17.1	48.8	30.3	25.6	3.4	54.02	24.33	5.2	Corn (wheat).
	1932 composite	24.6	24.3	27.3	1.01	27.0	25.7	44.0	26.6	23.5	3.3				
	1932 wash-off	31.9	36.2		.88		6.6	48.8	38.9	33.6	5.2	1.56	4.17	1.4	Wheat.
4	Profile composite	24.5	24.7	29.8	.99	30.1	24.9	42.9	27.6	22.0	3.8				
	1931 composite	25.7	26.1	38.5	.98	39.3	23.7	46.5	26.0	23.6	3.1				
	1931 wash-off	32.4	36.6	52.0	.89	58.4	11.8	46.1	38.3	33.2	2.1	3.21	8.26	.9	Wheat (clover).
	1932 composite	24.3	23.9	22.1	1.02	21.7	25.4	44.5	26.1	23.8	3.4				
	1932 wash-off	30.6					20.2	37.8	37.2	34.0	4.0	.20	1.06	.7	Clover.
5	Profile composite	26.1	25.3	27.4	1.03	26.6	23.4	44.6	27.4	23.2	4.1				
	1931 composite	26.5	26.8	36.2	.99	36.5	22.6	45.5	28.0	25.0	3.4				
	1931 wash-off	36.3	36.6	40.8	.99	41.2	10.8	43.1	42.4	38.4	2.7	1.71	10.51	.4	Do.
	1932 composite	25.0	24.5	21.9	1.02	21.5	24.0	44.8	27.0	24.3	3.6				
	1932 wash-off	27.2	30.3	53.5	.90	59.4	13.3	47.1	35.1	28.6	3.9	19.63	16.31	4.5	Do.
6	Profile composite	26.0	24.9	27.8	1.04	26.7	23.1	44.5	28.2	24.5	3.6				
	1931 composite	25.3	26.6	34.8	.95	36.6	22.8	45.4	28.3	23.5	2.9				
	1931 wash-off	39.5	38.2	40.0	1.03	38.8	10.6	42.0	43.8	39.4	2.6	.97	8.14	.3	Clover (fertilizer).
	1932 composite	25.2	25.3	21.8	1.00	21.8	22.4	46.9	27.0	22.4	3.4				
	1932 wash-off	31.1	33.1	50.9	.94	54.1	12.6	45.0	37.5	31.8	4.5	9.82	9.49	3.8	Corn.

7	Profile composite	25.1	24.3	26.1	1.03	25.3	22.5	47.1	25.6	22.5	4.1			
	1931 composite	24.8	26.7	38.1	.93	41.0	23.5	45.3	27.4	24.0	3.4			
	1931 wash-off	37.0	38.9	41.2	.95	43.4	15.6	39.8	40.8	35.3	2.9	.39	2.18	.4	Alfalfa (fertilizer).
	1932 composite	26.3	25.2	18.3	1.04	17.6	22.8	45.6	27.8	24.9	3.5			
	1932 wash-off											.00	1.12	0	Alfalfa.
8	Profile composite	27.5	25.5	26.7	1.08	24.7	21.8	46.6	26.8	24.4	4.0			
	1931 composite	26.2	27.3	36.2	.96	37.7	22.3	46.2	27.8	24.8	3.2			
	1931 wash-off	40.3	40.6	44.8	.99	45.3	8.1	44.3	43.6	40.4	3.2	.89	11.12	.2	Timothy.
	1932 composite	27.2	25.2	21.6	1.08	20.0	22.2	46.7	27.0	22.6	3.8				
	1932 wash-off											.00	1.56	0	Grass.
9	Profile composite	25.8	25.5	26.9	1.01	26.6	23.0	46.8	26.6	23.3	3.0			
	1931 composite	27.8	27.5	35.7	1.01	35.3	21.3	45.0	30.1	26.6	2.9			
	1931 wash-off	25.8	27.9	55.1	.92	59.8	15.6	49.7	30.7	26.5	3.4	108.44	19.74	12.9	Fallow.
	1932 composite	27.9	24.9	23.2	1.12	20.7	22.3	45.0	28.7	26.0	3.5				
	1932 wash-off	26.7	24.0	51.5	1.11	46.4	15.4	45.9	34.7	29.1	3.5	84.15	25.83	12.0	Do.
10 [4]	Profile composite	43.2	29.3	15.9	1.47	10.8	19.9	36.1	41.9	39.2	1.8				
	1931 composite	41.4	31.4	25.3	1.32	19.2	20.1	33.7	43.5	39.2	2.2				
	1931 wash-off	40.6	30.1	29.4	1.35	21.8	15.7	36.9	45.3	41.7	1.5	71.93	20.35	8.3	Do.
	1932 composite	41.4	29.7	23.1	1.39	16.6	20.1	34.5	43.1	39.8	2.0				
	1932 wash-off	47.5	30.7	31.9	1.55	20.6	11.9	32.2	53.8	48.6	1.9	43.10	19.78	8.1	Do.
Average [5]	Profile composite	25.6	25.1	27.6	1.02	27.0	22.4	46.0	27.3	23.0	3.7				
	1931 composite	25.7	26.6	36.9	.96	38.3	22.4	46.3	27.7	24.1	3.0				
	1931 wash-off	32.1	37.6	48.9	.95	52.0	13.8	46.0	36.4	32.1	2.9	40.06	15.84	3.9	
	1932 composite	25.6	24.8	22.0	1.03	21.3	23.1	45.2	27.8	24.2	3.4				
	1932 wash-off	28.0	29.5	53.2	.94	56.8	14.6	45.6	35.3	29.8	4.0	24.02	10.44	4.9	

[1] Determinations by H. W. Lakin, T. M. Shaw, and F. P. Trilety.
[2] Lower half of plot 1 (long plot).
[3] Upper half of plot 1.
[4] Desurfaced plot.
[5] Average does not include desurfaced plot.

NOTE.—Profile composite samples were taken to a depth of 8 inches.

TABLE 20.—*Analyses of annual composite samples and wash-off of Cecil sandy clay loam, Statesville, N.C.; with related data* [1]

[Total rainfall 44.35 inches in 1931, 50.52 inches in 1932; 10 percent slope]

Plot no.	Sample	Colloid by water-vapor absorption	Moisture equivalent	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Sand	Silt	Clay	Colloid <0.002 mm	Organic matter by H_2O_2	Erosion	Run-off	Erosion per inch of run-off	Crop treatment
		Percent	*Percent*				*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Tons per acre*	*Percent*	*Tons per acre*	
1 [2]	Profile composite	42.0	25.3	15.4	1.66	9.3	33.2	13.4	53.0	47.0	0.2				
	1931 composite	35.2	22.3	23.6	1.58	14.9	40.3	15.1	43.2	38.7	1.2				
	1931 wash-off	29.2	19.4	15.9	1.50	10.6	46.0	13.2	39.5	34.5	.9	17.46	10.99	3.59	Cotton.
	1932 composite	36.0	22.0	19.0	1.64	11.6	39.7	13.4	45.0	38.7	1.6				
	1932 wash-off	32.6	19.8	15.4	1.65	9.3	42.9	13.2	42.6	38.4	.9	7.53	6.94	2.14	Do.
2 [3]	Profile composite	38.8	23.3	16.7	1.67	10.0	34.6	14.8	50.2	44.1	.2				
	1931 composite	40.7	24.2	15.7	1.68	9.3	36.9	17.0	44.9	43.7	.9				
	1931 wash-off	30.9	20.9	19.0	1.48	12.8	43.4	14.0	41.3	35.2	1.1	19.71	11.38	3.91	Corn and cowpeas.
	1932 composite	38.1	22.8	17.9	1.67	10.7	40.1	13.5	47.1	41.0	1.0				
	1932 wash-off	27.9	18.8	19.9	1.48	13.4	47.5	12.8	38.5	33.4	.7	4.70	3.69	2.53	Cotton (rye and vetch).
3 [3]	Profile composite	43.0	26.0	14.3	1.65	8.7	31.8	10.4	57.0	52.8	.4				
	1931 composite	42.3	24.6	17.0	1.72	9.9	35.6	12.9	50.2	46.4	1.0				
	1931 wash-off	32.8	20.8	10.3	1.58	6.5	42.2	14.3	42.2	36.7	.8	20.26	7.29	6.27	Do.
	1932 composite	39.5	23.1	19.1	1.71	11.2	37.2	13.0	48.3	41.8	1.1				
	1932 wash-off	34.3	21.0	21.6	1.63	13.2	42.4	13.3	43.4	39.6	.5	3.15	5.49	1.14	Corn and cowpeas.
4	Profile composite	29.5	22.4	19.8	1.32	15.0	40.3	12.9	45.8	40.7	.7				
	1931 composite	29.8	22.0	17.2	1.35	12.7	43.7	16.8	36.7	31.5	2.3				
	1931 wash-off	21.7	20.8	24.5	1.04	23.5	49.1	15.5	33.0	27.8	1.8	64.79	26.20	5.58	Fallow.
	1932 composite	31.2	21.8	22.5	1.43	15.7	42.6	15.7	39.2	32.3	1.9				
	1932 wash-off	20.0	18.0	30.8	1.11	27.7	55.8	13.7	28.4	23.6	1.4	57.34	36.98	3.07	Do.
5	Profile composite	27.4	22.5	20.8	1.22	17.1	42.8	14.7	40.9	36.1	1.1				
	1931 composite	29.3	21.8	15.1	1.34	11.3	42.7	16.6	37.1	33.0	1.3				
	1931 wash-off	27.2	22.0	21.5	1.24	17.3	41.8	16.5	40.0	34.3	1.4	17.22	13.62	2.85	Corn and wheat.
	1932 composite	31.4	21.8	20.1	1.44	14.0	44.2	15.5	38.1	30.7	1.8				
	1932 wash-off	24.0	18.2	24.7	1.32	18.7	54.3	12.6	31.5	27.0	1.2	3.45	16.34	.38	Wheat and lespedeza.
6	Profile composite	28.9	22.6	22.0	1.28	17.2	42.9	10.4	46.1	40.4	.3				
	1931 composite	31.2	23.3	18.4	1.34	13.7	43.5	16.8	38.2	33.8	1.3				
	1931 wash-off	38.0	40.2	38.9	.95	40.9	19.3	21.3	54.9	38.1	3.4	.81	9.60	.19	Lespedeza.
	1932 composite	29.9	22.1	20.4	1.35	15.1	44.2	15.5	38.1	31.1	1.7				
	1932 wash-off											.00	1.06	.00	Do.
7	Profile composite	32.2	23.1	21.6	1.39	15.5	41.6	11.6	45.8	41.0	.8				
	1931 composite	31.3	23.4	18.2	1.34	13.6	43.0	15.7	38.8	34.2	2.0				
	1931 wash-off	33.9	31.4	36.2	1.08	33.5	27.2	20.8	47.8	38.4	2.9	2.22	11.31	.44	Do.
	1932 composite	30.4	22.0	19.9	1.38	14.4	43.7	11.8	42.3	29.7	1.9				
	1932 wash-off	28.8	22.3	22.6	1.29	17.5	41.8	11.5	43.9	36.4	1.9	2.46	4.80	1.02	Cotton.

8	Profile composite	32.7	22.3	21.6	1.47	14.7	41.1	12.4	45.6	39.6	.6			
	1931 composite	32.8	22.9	18.3	1.43	12.8	43.3	16.1	38.2	33.0	2.0			
	1931 wash-off	30.6	22.9	19.3	1.34	14.4	37.6	17.4	43.5	37.6	1.2	11.95	14.16	1.90	Do.
	1932 composite	32.2	22.7	22.4	1.42	15.8	40.8	17.6	40.1	32.8	1.2				
	1932 wash-off	30.3	21.1	16.9	1.44	11.7	43.4	19.6	36.1	33.0	.5	5.18	5.11	2.01	Corn.
9	Profile composite	30.4	23.1	17.6	1.32	13.4	40.7	17.3	40.7	34.4	.8				
	1931 composite	32.0	23.2	15.8	1.38	11.4	42.5	20.0	35.2	33.1	2.0				
	1931 wash-off	31.2	32.4	32.8	1.15	28.5	24.3	32.5	39.6	37.8	2.6	9.12	14.62	1.41	Sod.
	1932 composite	36.8	24.1	27.9	1.53	18.3	40.8	16.8	40.5	34.3	1.4				
	1932 wash-off											.00	1.13	.00	Do.
10	Profile composite	32.1	23.8	22.7	1.35	17.2	40.0	18.2	41.2	35.2	.4				
	1931 composite	33.9	23.6	14.5	1.44	10.1	40.7	17.9	39.7	35.0	1.2				
	1931 wash-off	34.4	23.1	20.6	1.49	13.8	46.5	18.3	33.4	26.8	1.4	11.88	11.65	2.30	Cotton.
	1932 composite	33.8	23.1	23.3	1.46	16.0	40.7	18.2	39.7	34.4	1.1				
	1932 wash-off	31.9	21.2	24.7	1.50	16.5	42.9	14.2	42.0	33.7	.6	4.95	5.76	1.70	Do.
11 [3]	Profile composite	29.7	21.8	19.4	1.36	14.3	41.3	20.5	37.9	32.0	.2				
	1931 composite	32.9	22.7	13.2	1.45	9.1	41.7	17.4	39.7	33.7	.8				
	1931 wash-off	30.9	23.5	23.9	1.32	18.1	38.3	19.7	39.8	31.7	1.8	18.16	9.53	4.29	Do.
	1932 composite	31.2	21.8	18.8	1.43	13.1	41.6	17.7	38.9	27.9	1.2				
	1932 wash-off	34.4	22.0	18.1	1.56	11.6	38.7	16.5	43.3	37.1	1.1	5.66	4.00	2.80	Do.
12 [4]	Profile composite	36.1	23.5	19.2	1.54	12.4	37.5	9.9	51.3	44.3	.9				
	1931 composite	36.5	24.1	16.5	1.52	10.9	38.9	15.0	44.4	39.6	1.3				
	1931 wash-off	32.0	22.6	22.9	1.42	16.1	41.8	17.2	39.2	33.0	1.5	13.77	13.68	2.27	Do.
	1932 composite	39.0	24.4	17.7	1.60	11.1	37.7	14.9	45.7	40.2	1.3				
	1932 wash-off	35.5	21.8	21.0	1.63	12.9	40.0	13.0	45.1	39.0	1.4	8.20	9.80	1.67	Do.
Average [5]	Profile composite	31.0	22.8	20.5	1.36	15.2	40.9	14.2	43.9	38.2	.6				
	1931 composite	32.2	23.0	16.4	1.40	11.7	42.2	16.9	38.7	34.1	1.6				
	1931 wash-off	31.8	26.5	26.7	1.23	22.9	36.2	19.9	41.2	33.9	2.0	16.66	13.82	2.36	
	1932 composite	32.9	22.6	21.4	1.45	14.8	41.8	16.0	40.3	32.6	1.5				
	1932 wash-off	29.3	20.7	22.7	1.41	16.7	45.3	14.4	38.6	32.8	1.2	9.66	9.44	1.41	

[1] Mechanical analyses by H. W. Lakin and T. M. Shaw.
[2] Desurfaced plot.
[3] Long plot.
[4] Short plot.
[5] Average does not include desurfaced plots.

NOTE.—Profile composite samples taken to a depth of 7 inches.

TABLE 21.—*Analyses of composite surface samples and wash-off of Marshall silt loam, Clarinda, Iowa; and related data* [1]

[Total rainfall in 1932, 28.76 inches; June 1 to Dec. 31, 21.15 inches; slope 9.64 percent]

Plot no.	Sample	Colloid by water-vapor absorption	Moisture equivalent	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Sand	Silt	Clay	Colloid <0.002 mm	Organic matter by H_2O_2	Erosion [2]	Run-off [2]	Erosion per inch of run-off	Crop treatment
		Percent	*Percent*				*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Tons per acre*	*Percent*	*Tons per acre*	
1 [3]	Profile composite	33.3	30.4	26.0	1.10	23.6	2.2	60.4	34.1	29.9	3.1				
	1932 composite	32.3	27.6	18.2	1.17	15.6	2.1	61.9	32.9	29.2	2.9				
	1932 wash-off	26.5	28.4	56.6	.93	60.9	2.5	60.8	33.7	33.1	2.6	42.81	18.7	10.8	Corn.
2 [4]	Profile composite	33.4	30.6	27.0	1.09	24.8	2.1	59.6	34.9	30.5	3.1				
	1932 composite	33.7	28.2	17.0	1.20	14.2	2.2	59.8	34.6	30.8	2.9				
	1932 wash-off	26.2	28.5	58.4	.92	63.5	2.2	65.6	29.1	28.3	2.7	43.46	21.1	9.7	Do.
3	Profile composite	32.2	30.3	29.7	1.06	28.0	2.4	58.2	35.8	30.6	2.9				
	1932 composite	33.5	28.3	17.6	1.18	14.9	2.0	60.9	33.8	29.4	2.9				
	1932 wash-off	26.7	28.2	53.8	.95	56.6	2.8	62.0	32.0	27.4	2.9	42.07	23.0	8.7	Do.
4	Profile composite	32.9	30.4	26.1	1.08	24.2	1.8	60.4	34.5	29.7	3.1				
	1932 composite	33.6	28.8	15.4	1.17	13.2	2.2	61.0	33.5	29.0	2.9				
	1932 wash-off	25.6	27.5	52.9	.93	56.9	2.5	59.6	34.9	30.8	2.7	49.15	27.6	8.4	Do.
5	Profile composite	32.9	29.7	26.0	1.11	23.4	1.8	61.1	33.7	29.7	2.6				
	1932 composite	30.8	28.0	15.8	1.10	14.4	2.1	60.9	33.8	28.5	2.7				
	1932 wash-off	27.9	30.4	58.2	.92	63.2	1.9	61.0	33.8	29.4	3.0	1.36	8.8	.7	Oats.
6	Profile composite	31.9	29.7	26.1	1.07	24.4	2.0	60.7	33.9	29.7	3.0				
	1932 composite	32.4	28.2	17.6	1.15	15.3	2.5	58.9	35.0	30.3	3.0				
	1932 wash-off	29.2	31.7	60.2	.92	65.4	2.2	60.0	34.9	29.8	2.6	.80	9.4	.4	Clover.
7	Profile composite	32.6	30.2	27.7	1.08	25.6	2.0	61.7	33.3	30.4	2.2				
	1932 composite	32.6	28.2	15.5	1.16	13.4	2.2	58.8	35.3	31.0	2.9				
	1932 wash-off	27.2	30.3	57.1	.90	63.5	2.6	61.4	33.0	27.9	2.8	1.15	13.8	.4	Alfalfa.
8	Profile composite	32.7	30.2	28.1	1.08	26.0	1.5	60.7	34.6	29.9	2.3				
	1932 composite	32.9	28.7	18.9	1.15	16.5	2.0	58.9	35.1	30.4	3.2				
	1932 wash-off	27.8	29.9	57.3	.93	61.6	2.6	60.4	33.7	29.2	2.9	1.19	13.9	.4	Bluegrass.
9 [5]	Profile composite	40.5	33.0	18.3	1.23	14.9	1.1	54.5	42.1	35.5	1.8				
	1932 composite	40.9	31.1	12.4	1.32	9.4	1.1	56.4	40.2	35.6	1.7				
	1932 wash-off	32.4	29.0	36.8	1.12	32.9	1.6	59.0	36.8	34.2	2.1	39.30	14.7	12.6	Corn.
Average [6]	Profile composite	32.7	30.2	27.1	1.08	25.0	2.0	60.4	34.4	30.1	2.8				
	1932 composite	32.7	28.3	17.0	1.16	14.7	2.2	60.1	34.3	29.8	2.9				
	1932 wash-off	27.1	29.4	56.8	.93	61.5	2.4	61.4	33.1	29.5	2.8	22.75	17.0	4.9	

[1] Mechanical analyses by H. W. Lakin and T. M. Shaw.
[2] Erosion and run-off data for 7 months only.
[3] Short plot.
[4] Long plot.
[5] Desurfaced plot.
[6] Average does not include desurfaced plot.

NOTE.—Profile composite samples were taken at depths ranging from 6 to 18 inches.

TABLE 22.—*Analyses of annual composite samples and wash-off of Nacogdoches fine sandy loam, at Tyler, Tex.; and related data* [1]

[Total rainfall 36.10 inches in 1931, 46.71 inches in 1932; 10 percent slope]

Plot no.	Sample	Colloid by water-vapor absorption	Moisture equivalent	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Sand	Silt	Clay	Colloid <0.002 mm	Organic matter by H_2O_2	Erosion [2]	Run-off [2]	Erosion per inch of run-off	Crop treatment
		Percent	*Percent*				*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Tons per acre*	*Percent*	*Tons per acre*	
	Profile composite	20.8	14.2	23.8	1.46	16.3	69.9	10.1	18.0	17.2	1.5				
	1931 composite	19.6	14.3	22.3	1.37	16.3	59.3	9.4	19.0	18.0	1.6				
1 [3]	1931 wash-off	37.6	36.9	62.0	1.03	60.2	38.5	19.4	34.8	28.9	6.5	1.20	15.0		Cotton.
	1932 composite	21.4	14.0	21.5	1.53	14.0	69.3	9.9	18.7	15.6	1.6				
	1932 wash-off	18.9	16.2	62.0	1.17	53.0	72.0	6.3	18.7	10.9	2.0	3.18	15.0	0.45	Do.
	Profile composite	21.5	15.1	24.9	1.42	17.5	69.7	8.7	19.3	16.8	1.8				
	1931 composite	23.2	15.4	19.5	1.51	12.9	66.9	9.2	21.9	19.8	1.6				
2	1931 wash-off	38.8	40.5	58.7	.96	61.2	35.3	19.2	36.2	28.0	8.4	.93	14.1		Do.
	1932 composite	25.2	14.6	20.6	1.73	11.9	68.5	10.5	19.2	16.1	1.4				
	1932 wash-off	25.1	20.7	60.4	1.21	49.9	55.3	15.2	24.8	21.5	4.3	4.06	16.6	.52	Do.
	Profile composite	19.9	15.7	27.4	1.27	21.6	69.2	10.3	18.0	15.1	2.1				
	1931 composite	21.1	15.7	19.9	1.34	14.9	68.5	9.2	20.2	17.5	1.7				
3	1931 wash-off											.06	3.4		Bermuda grass.
	1932 composite	21.7	15.2	22.3	1.43	15.6	70.2	10.9	16.6	13.7	2.1				
	1932 wash-off	62.4										.00	1.7		Do.
	Profile composite	51.2	25.9	17.1	1.98	8.6	49.0	5.0	45.2	44.0	.2				
	1931 composite	52.6	25.5	13.8	2.06	6.7	45.0	5.3	48.9	47.5	.4				
4 [4]	1931 wash-off	50.3	23.7	16.1	2.12	7.6	40.3	5.1	53.5	51.4	.7	18.49	15.0		Cotton.
	1932 composite	49.3	24.5	19.6	2.01	9.7	47.2	6.5	45.6	43.7	.5				
	1932 wash-off	48.7	22.6	19.7	2.15	9.2	[5] 43.2	6.3	49.5	48.7	.7	[5] 29.48	[5] 21.1	2.99	Do.
	Profile composite	20.7	15.0	25.4	1.38	18.5	69.6	9.7	18.4	16.4	1.8				
	1931 composite	21.3	15.1	30.6	1.41	14.7	64.9	9.3	20.4	18.4	1.6				
Average [6]	1931 wash-off	38.2	38.7	60.4	1.00	60.7	36.9	19.3	35.5	28.5	7.5	.73	10.8		
	1932 composite	22.8	14.6	21.5	1.56	13.8	69.3	10.4	18.2	15.1	1.7				
	1932 wash-off	35.5	18.5	61.2	1.19	51.5	63.7	10.8	21.8	16.2	3.2	2.41	11.1	.32	

[1] Mechanical analyses by H. W. Lakin and T. M. Shaw.
[2] Erosion and run-off data for 1931 are for 6 months only.
[3] Short plot.
[4] Desurfaced plot.
[5] Includes estimates of losses from 1 rain as a water boil caused the tank to run over.
[6] Average does not include desurfaced plot.

NOTE.—Profile composite samples were taken to a depth of 8 inches, except desurfaced plot, which was sampled to a depth of 18 inches.

Since, as already mentioned, the data available at present are not sufficient to justify final conclusions, these tables will not be discussed in detail. Attention will merely be drawn to certain special features and general relations.

Throughout the plots it is to be generally expected that the wash-off material should be considerably different from surface composites. It would appear that the more readily dispersed and transported material would be removed to a greater extent than the coarser particles. Inspection of the tables shows that in the Shelby, Colby, Nacogdoches, and Vernon soils there is a marked increase in clay and colloid content and in the moisture equivalent of the wash-off, as compared with the plot composites. In the other four soils but little difference is to be noted. Practically in every case the organic content of the wash-off is greater than in the soil composite.

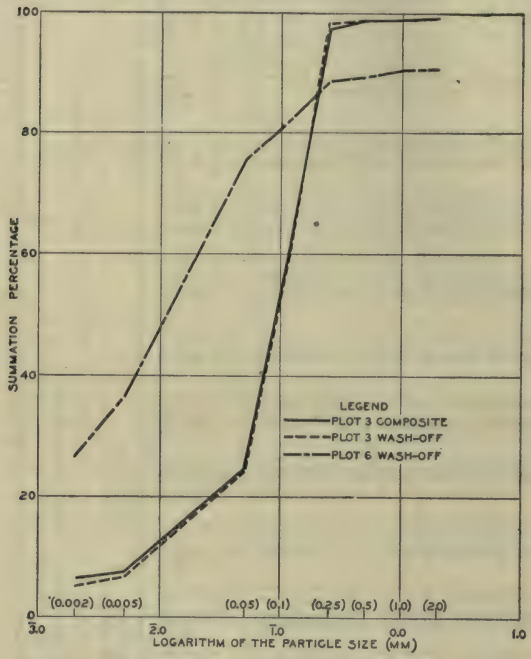

FIGURE 7.—Comparison of the mechanical composition of wash-off and plot composite samples of Vernon fine sandy loam, 1932

The water-vapor absorption of the wash-off is somewhat decreased by the removal of soluble salts and by consequence the colloid content as determined by the water-vapor-absorption method is relatively less than is shown by mechanical analysis. The moisture equivalent is relatively less affected by the loss of soluble salts and consequently the colloid-moisture equivalent ratio is usually less for wash-off than for the soil.

In general the mechanical composition of the wash-off varies with the quantity of eroded material. Plots in cultivated crops, as well as those bare or in fallow, have the greatest erosion and the eroded material is increasingly similar to the plot composite. Those in noncultivated crops such as wheat, grass, lespedeza, etc., have low erosion and the eroded material differs more widely from the soil. This is illustrated by figure 7.

In figure 7 the mechanical analysis of wash-off from plot 6 of the Vernon fine sandy loam is compared with that from plot 3. The mechanical analyses of the two plots are essentially identical. The wash-off, however, of plot 3 is 68.5 tons per acre; that from plot 6 is but 0.56 ton.

In figure 7 the summation percentages of the mechanical analysis fractions are plotted against the logarithm of the particle sizes after

the method of G. W. Robinson (*18*). It should be noted that in the method of mechanical analysis used in this laboratory the colloid <0.002 mm is included in the clay. Since organic matter is included in the mechanical analysis but without respect to particle size, the organic content does not appear in the curves and therefore the curves show also, by the degree of divergence from 100 percent, the relative amounts of organic matter in the samples.

Inspection of these curves shows the very close similarity of the heavy wash-off of plot 3 to the original soil and the wide difference shown by the light wash-off from plot 6. The most striking points shown by figure 7 are the increased relative amounts of colloid and organic matter in the wash-off from plot 6 as compared with plot 3. The data in table 15 may be used to show that while plot 3 lost 122 times as much soil as plot 6, it lost but 23 and 22 times as much colloid and organic matter, respectively. Since colloid and organic matter are important constituents of the soil with respect to plant growth, it may readily be seen that damage by erosion is not necessarily proportional to extent of erosion. Slight erosion may be relatively more detrimental to fertility than severe erosion.

Another feature of slight erosion is shown by plot 8 of the Kirvin fine sandy loam (table 16). This plot is in grass, and erosion is very slight—1.8 pounds of oven-dry material in the wash-off sample. The run-off material amounted to 0.081 pound. If the run-off residue be considered as wholly colloid, as it certainly is for the most part, this quantity would increase the wash-off colloid from 4.7 to 8.8 percent. This indicates that 47 percent of the colloid removed is lost in the run-off. This behavior of the colloid is general and is especially marked in those soils where, though dispersion is difficult, coagulation of colloid also is slow. It is probable therefore that in all cases where erosion is small a quantity of colloid in excess of its relative amount in the soil is removed by erosion.

It is difficult to correlate mathematically the mechanical composition of the wash-off with the quantity of wash-off on the various plots because of the number of different components shown by mechanical analysis. The moisture equivalent, however, is a very good index of mechanical composition, particularly when the components of the material are all derived from the same soil (*13*). Therefore the correlation coefficients between the moisture equivalents and the quantity of wash-off have been calculated (*22*) and are shown in table 23.

TABLE 23.—*Correlation coefficient between the moisture equivalent of the wash-off and the quantity of wash-off*

Soil type	1931 wash-off	1932 wash-off
	r	r
Kirvin fine sandy loam	−0.87	[1]−0.32
Vernon fine sandy loam [2]	−.71	−.76
Cecil sandy clay loam	−.57	−.63
Shelby silt loam	−.94	−.96
Colby silty clay loam	−.92	+.59
Marshall silt loam		−.93
Houston black clay	+.04	+.11

[1] Omitting plot 8, $r=-0.92$.

[2] For 1930 wash-off, $r=-0.60$.

In all but three cases there is a definite negative correlation coefficient. This means that the moisture equivalent decreases relatively with increase of wash-off. Since moisture equivalent is primarily, though not wholly, dependent upon colloid content and organic matter, this result again emphasizes the fact that more coarse material is removed when the wash-off is greater; hence the deleterious effect of erosion is relatively greater the smaller the quantity of wash-off. In the case of the Houston black clay the correlation coefficient is positive but is so small that it indicates no material difference in this soil whether the erosion be small or great. This soil not only is dispersed with difficulty but the mechanical composition is largely silt and clay. Consequently, the soil may be expected to move practically as a whole if it moves at all. In the case of the Colby, the 1931 wash-off behaves normally but the 1932 samples of wash-off show a positive correlation coefficient which would seem to indicate that in 1932 the wash-off has distinctly more colloid content than corresponds to its relative amount. No explanation of this anomalous behavior is at hand and it will be of interest to observe in future samples whether it continues to behave in this manner.

In tables 15 to 22 are included the data of the plot composites, which are taken annually to a depth of 7 inches, for 1931 and 1932. In general, it is not to be expected that these samples should yet show any marked changes in comparison with each other. They are usually somewhat different in character from the surface plot profile composites, also given in the tables. The latter samples, the plot profile composites, are taken to the depths corresponding to the A horizon for each soil. The tabulated data do not show any differences which may not be accounted for by experimental error, except in the case of the Shelby silt loam (table 19) for plot 9.

In this plot, which was fallow in both 1931 and 1932, the quantity of erosion is exceptionally high, being 193 tons per acre for the 2 years. This corresponds to a removal of the surface of the plot to a depth of 1.2 inches, since this soil weighs 162 tons per acre-inch. The A horizon of this soil is but 8 inches in depth; therefore, the removal of so large a quantity of soil results in the inclusion in the 7-inch plot composite of a portion of the B horizon. The A horizon has a normal content of 24.3 percent of colloid and the B 48.7 percent (*16, table 1*). This type of alteration may be expected to appear in all the plots of the various stations when erosion shall have progressed sufficiently. In the case of the soils having deep A horizons, as in the Palouse silt loam, and in those of fairly uniform texture in the upper horizons, as in the Houston black clay and Colby silty clay loam, these differences should be slow in appearing. They cannot yet be noted. In the case of the Cecil soil the profile plot composites were taken to a depth of 7 inches, although the surface horizon is but 6 inches. Further, the plot composites are quite variable in their colloid content. Despite these unsatisfactory data the composite of plot 4, which has the maximum erosion, begins to show increasing influence of the B horizon. It should also be mentioned that the control plots at the erosion experiment stations are somewhat protected from gully erosion by the limited length of the plots and the lip of the catchment tanks. The erosion shown by them is therefore not strictly comparable with field conditions.

The erosion and rainfall data shown in tables 14 to 21 are taken from the annual progress reports of the various erosion experiment stations. Access to these reports, not yet published, was given us through the courtesy of H. H. Bennett, until recently the director of these stations.

When an attempt is made to compare the relationships shown by the soil data and erosion results at the different stations with each other, serious difficulties are encountered. These arise from the following circumstances. While the general set-up of the plots and their management is the same at all the stations, yet the kind of crop treatment, slope of plots, amount and character of the rainfall, and temperature changes are all quite varied. It is therefore problematical how far the influence of the character of the soil, as shown by analytical data, may be traced. Were it possible to hold all other variables constant except soil composition as expressed by structure, texture, and chemical character, the problem would be relatively easy.

The situation at the Tyler station closely approximates these conditions in that the Kirvin fine sandy loam and Nacogdoches fine sandy loam plots are located on areas of nearly the same slope; the former at 8¾ percent, the latter at 10 percent. There are, however, but 3 normal plots of the Nacogdoches and 9 of the Kirvin. The climatic conditions are of course identical. If comparison be limited to plots receiving identical treatment, certain definite conclusions may be reached. A comparison of tables 1 and 4 shows that the surface horizon of the Nacogdoches is lower than that of the Kirvin in respect to the silica-sesquioxide ratio, the base content, the suspension percentage, the dispersion ratio, and the percolation ratio. It is higher in the water content of the soil colloid acid, the colloid-moisture equivalent ratio, and colloid content.

The physical properties which are correlated by the erosion ratios indicate a much lower rate of erosion for the Nacogdoches soil.

The erosion ratio seems to represent the erosional characteristics of the soils better than any other single criterion. It is therefore of special interest to compare the directly comparable plots of these two soils with respect to the erosion ratio and the actual erosion (table 24)

TABLE 24.—*Comparison of erosion ratio and erosion of Nacogdoches fine sandy loam and Kirvin fine sandy loam under identical conditions, 1932*

Plot no.	Soil	Erosion ratio	Erosion	Crop
			Tons per acre	
1 [1]	Nacogdoches	14.0	3.18	Cotton.
1 [1]	Kirvin	43.8	12.36	Do.
2	Nacogdoches	11.9	4.06	Do.
3	Kirvin	46.8	17.48	Do.
3	Nacogdoches	15.6	.00	Grass.
8	Kirvin	44.3	.09	Do.
4 [2]	Nacogdoches	9.7	29.48	Cotton.
12 [2]	Kirvin	5.6	73.66	Do.

[1] Short plot.
[2] Desurfaced plot.

Inspection of table 24 shows a very close correlation for the normal plots. In the grass plots the erosion is so small in both cases as to obscure any marked difference of behavior. The total lack of harmony between the erosion ratios and the erosion in the desurfaced

plots is in part accounted for by the greater run-off on the Kirvin plots (tables 16 and 22) despite the higher colloid percentage. Another factor tending to distort the results is that the desurfaced plots are not nearly so well protected from erosion by the crop as are the surface horizons of the same soil. This is because of poor growth upon the desurfaced plots. It is in general true that desurfaced plots show a higher erosion than corresponds to their erosion ratios.

In comparing the erosional characteristics of the soils at the different stations with the natural erosion which occurs in the field, one of the more disturbing influences is in the character and quantity of the rainfall. With a given soil one might logically expect that other things being equal the quantity of erosion would be directly proportional to the quantity of precipitation. During a term of years this is probably the case. However, in a short period the quantity effect may be wholly obscured by the relative intensities of the precipitation. An example of this influence is found in the results at the Statesville Erosion Station (table 20). In 1931 the mean erosion from the plots was 16.65 tons per acre, with a rainfall of 44.35 inches. In 1932 the erosion was but 9.66 tons per acre and the rainfall 50.52 inches. The explanation of this wide difference may probably be found in the extremely heavy, almost torrential, rains of 1931.

The usual effect of alteration of rainfall is illustrated by the results at the Guthrie Station (table 15) where for 1930, 1931, and 1932 the mean erosion on the plots was 11.05, 7.34, and 32.40 tons per acre, while the rainfall was 33.66, 29.20, and 37.40 inches, respectively. The mean run-off in inches was 4.02, 3.28, and 5.19 inches, respectively. It is obvious that the amount of erosion is proportional to some function of the run-off but what that function is the available data are not sufficient to determine. It is true also that considerable modification in the results obtained may be expected depending upon whether precipitation occurs as rain or snow and upon ground frozen or already saturated with water.

Topographical conditions must also be taken into account in considering the erosive effects of rainfall. Among these perhaps the most important are the length and degree of the slopes which are subject to erosion. At all the stations 1 or 2 plots longer or shorter than the normal plots have been included in the set-up. It was to have been expected that erosion would increase with the length of the plot on a given slope. Only in one instance, the Kirvin soil at Tyler, Tex., has this been consistently true (table 16). At the other stations the reported results are variable. Only at the Tyler Station have plots been established which are designed to show the effect of differences of slope on erosion. No laboratory studies have, as yet, been made upon the eroded material from these plots. The field results at present available are not sufficient to permit the drawing of definite conclusions. Neither can any definite deductions be drawn from the erosion data of the different stations as to the effect of degree of slope upon erosion.

It is not within the province of this bulletin to discuss the effects of crop cover and of cultivation upon erosion, but it is evident that these have an important bearing upon the field problems and should be mentioned in this connection because they affect the conclusions to be drawn from the field data with reference to laboratory results.

When the various conditions which affect erosion are considered it becomes evident that great difficulties are encountered in any attempt to segregate the effects produced by differences in the soil. This is especially true when the attempt is made to estimate these effects quantitatively and to determine their causes. It is therefore of special interest to determine to what extent the erosion ratio correlates the soil composition with actual erosion. For this purpose the data given in table 25 have been segregated.

TABLE 25.—*Comparison of the average erosion ratio of the annual composite samples with the average erosion for 1931 and 1932; desurfaced plots not included*

Soil type	Average erosion ratio	Average erosion	Soil type	Average erosion ratio	Average erosion
		Tons per acre			*Tons per acre*
Kirvin fine sandy loam	45.9	15.2	Nacogdoches fine sandy loam [1]	13.8	2.4
Vernon fine sandy loam	42.3	19.9	Cecil sandy clay loam	13.3	13.2
Shelby silt loam	29.8	32.0	Houston black clay	8.7	5.1
Colby silty clay loam	18.6	9.0			
Marshall silt loam [1]	14.7	22.8	Average	23.4	15.0

[1] Data for 1 year only.

Attention has already been called to the total failure of the erosion ratio as a means of prediction of the behavior of the desurfaced plots (p. 57). In table 25 it will be seen that a fair general correlation exists for the surface soils. The soils having the greatest erosion ratios have high erosion losses but the quantitative comparison is not good. The outstanding exception is in the case of the Marshall, which, with an erosion ratio of less than average value, shows actual erosion above the average. It is to be observed that in the two sets of plots showing the widest variations, the Kirvin fine sandy loam and the Marshall silt loam, the slopes of the plots are 8.75 and 9.64 percent while for the two sets showing the closest correlation, the Houston black clay and the Colby silty clay loam, the slopes are 4 and 5 percent. Despite this poor showing it seems quite clear that the erosion ratio represents a fair qualitative indication of the behavior of a surface soil. Whether it can be used quantitatively along with other factors is not certain.

GENERAL REMARKS

It is not necessary to repeat in this bulletin the general remarks made in Technical Bulletin 316 (*16*). What is there said, however, is well borne out by the present data, so far as these apply. It is now proposed to study the plasticity, the shrinking, and the swelling volumes of these soils, with a view not only of relating these to the erosional problem, but also the chemical composition and texture of the soils. It is also proposed to study with great care the exchangeable base and acid content of these soils. While these studies are in progress field data will accumulate. It is to be hoped that eventually it may be possible to so correlate field data with laboratory examination as to permit the establishment of criteria by which the field behavior of soils may be predicted. If this becomes possible it will follow that appropriate conservation measures will also be indicated.

From the information at present available it would seem that eventually adequate data will be collected along all needed lines except with respect to the influence of slope.

The data being collected concerning these soils have a special value quite aside from their bearing upon erosion. These soils represent five of the great soil groups recognized in the classification of soils by the Division of Soil Survey. They therefore present exceptionally detailed information on a set of diverse soil types. It is to be hoped that these studies may be supplemented by like careful examination of other soil types within the same groups and particularly by studies of the great groups not represented by the erosion station soils. It would be of great interest were it possible to have detailed data concerning the chemical composition, physical properties, and field behavior of at least one soil type in each State. Such an accumulation of accurate and comparable information must be made before a full comprehension of soils can be reached.

SUMMARY

A previous bulletin on the soils of the erosion experiment stations presented much physical and chemical information concerning eight soil profiles. The present bulletin contains similar data for the three soil profiles from the more recently established stations and includes a large quantity of additional data for the soils of all the stations thus far established. The determinations made include mechanical analyses, chemical analyses of both soil and colloid, specific gravity, field volume weight, porosity, dispersion ratio, erosion ratio, moisture equivalent, and a number of other moisture relationships.

The soils of the erosion stations represent five of the great soil groups, and the wide divergence of the properties and composition of both soils and colloids occasion considerations of much theoretical importance. For example, the highly lateritic Nacogdoches series appears to contain a very weak acid which is assumed to be of the halloysitic type, and the iron oxide appears to be free and nearly anhydrous. By contrast the Colby series appears to contain a considerably stronger acid, assumed to be of the pyrophyllic type and the iron content appears to be a part of the silicate complex. Various ratios of theoretical interest are presented and the silica-combined water ratio is calculated and its significance discussed.

A series of experiments on the settling volume of soils is reported and from the results is deduced a new soil-water relationship which is called the water-saturation capacity. The relation of this soil property to the other soil-moisture properties is discussed and illustrated. It is pointed out that while the field volume weights are uniformly greater than the volume weights of the soils at their settling volume, yet there is a close correlation between these values. Attention is also directed to the influence of colloid composition, as well as of quantity of colloid, on soil-moisture relationships.

Determinations of the fundamental physical data of composite samples from each plot and of the eroded material from each plot are reported. A study of the eroded material shows marked differences in the quantity and character of the wash-off. When the quantity of eroded material is large it is similar in character to the whole soil. When the erosion is slight, the fine material predominates. Slight erosion, therefore, may be relatively more detrimental to fertility

than more severe erosion. These data supplemented by the field data on rainfall, run-off, and erosion reported from the stations show that erosional effects vary greatly with the kind of soil, the amount and intensity of rainfall, the kind of crop and cultivation, the slope, and perhaps other factors. Data for 2 years only are available. It is planned to follow these relations over a much longer period.

The laboratory determination most closely correlated with field erosion is the erosion ratio. Even this ratio has but qualitative significance. No definite relationship between the erosional behavior of soils and their properties as determined in the laboratory has been established. The influence of the soil itself is partially obscured by climatic and other influences.

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TECHNICAL BULLETIN No. 429 JULY 1934

PILE TRESTLES AS CHANNEL OBSTRUCTIONS

By

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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Technical Bulletin No. 429 July 1934

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

PILE TRESTLES AS CHANNEL OBSTRUCTIONS[1]

By DAVID L. YARNELL[2]

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INTRODUCTION

This bulletin presents the results of 1,082 experiments on the effect of clean pile trestles—that is, pile trestles free of any debris—in obstructing the flow of water made at the hydraulic laboratory of the University of Iowa at Iowa City, Iowa, during 1929 and 1930.

The investigations were undertaken primarily to determine the coefficients used in certain formulas for calculating the backwater caused by such obstructions.

Tests were conducted on both small-size models and on full-size single- and double-track pile trestles. The model trestles were made in the laboratory, whereas the material for the full-size trestles was furnished by the Chicago, Rock Island & Pacific Railway Co

PURPOSE OF THE STUDY

The erection of a pile trestle or a bridge pier in a stream forces the water to flow through a reduced cross section, and in passing this section the water must acquire a velocity greater than that existing in

[1] A report of a study made under a cooperative agreement between the Bureau of Agricultural Engineering of the U.S. Department of Agriculture and the College of Engineering of the University of Iowa.

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the unobstructed channel.[3] The increase in velocity can be produced only by elevating the water surface up stream from the trestle where the contracted area of flow exists. Thus as the stream enters the contracted area, a drop in the water surface is noted accompanying the increase in velocity.

The changes in cross section and velocity in passing the trestle piling cause much disturbance in the flow of water. Eddies may be formed along the piling. The high velocities and resultant eddies may scour out the bed of the stream next to the pile bents to such an extent that the trestle itself may be endangered and even swept away.

Differences of opinion often occur as to the amount of obstruction to flow caused by highway or railway pile trestle bridges and lawsuits may result over the amount of damages. It has been a moot question whether the resistance to flow offered by a double-track trestle with the bents for both tracks in line is greater than that offered by a single-track trestle. Just how much more obstruction is offered by a double-track trestle with the bents for the two tracks set a little off line than by the same track with the bents set in line has been an unanswered question. The hitherto existing need of information in this field is relieved by the results of these investigations as set forth herein.

The amount of obstruction a pile-trestle bent offers to the flow of water may easily be expressed in the form of a trestle-bent coefficient in a backwater formula. The value of the coefficient depends upon the particular formula used. Of the many formulas known, those most commonly used are D'Aubuisson's, Weisbach's, Nagler's, and Rehbock's. In the first three the trestle-bent coefficient varies with the quantity of flow. For a given height of backwater, depth of flow, and channel contraction, if the trestle coefficient is increased 5 percent through an improved setting of the bents, the flow capacity of the trestle is increased 5 percent. The trestle-bent coefficient is, in reality, an index number of the hydraulic efficiency of a pile-trestle bent.

The discharge through pile-trestle openings during floods may be computed with a fair degree of accuracy by means of a backwater formula if the drop-down at the trestle opening is known. The converse also is true; the discharge being known, the drop-down or backwater caused by the trestle may be determined.

The specific purpose of this investigation was to determine the proper coefficients for use in certain formulas so that these formulas can be used for computing the probable discharge or the probable drop-down at trestle openings. Experiments were made on models of $\frac{1}{100}$ size and $\frac{1}{4}$ size, and full-size single- and double-track pile-trestle bents placed both in line with and at various angles to the current.

THEORY OF THE OBSTRUCTION OF PILE TRESTLES TO FLOW OF WATER

Figure 1 represents a pile-trestle bent with the water flowing through the contracted area. The following symbols are used:

Q = quantity of water flowing, in volume per second.
D_1 = mean depth of water upstream from head of trestle at a distance equal to length of bent.
D_2 = mean depth of water in most contracted section of channel.

[3] It is assumed that the velocity of the water in the unobstructed channel is less than critical. If the velocity in the unobstructed channel is at the critical value or higher, then the water will rise at the point of obstruction. Such conditions of flow are seldom encountered in actual practice.

D_3 = mean depth of water in channel below contraction; that is, depth in unobstructed channel.
W_1 = mean width of channel above contraction.
W_2 = mean width of channel at most contracted section.
W_3 = mean width of channel below contraction, ordinarily equals W_1.
V_1 = mean velocity of water above contraction, Q/W_1D_1.
V_2 = mean velocity of water in most contracted section of channel, Q/W_2D_2.
V_3 = mean velocity of water in channel below contraction, Q/W_3D_3, ordinarily equal to Q/W_1D_3.
H_2 = drop of water surface at most contracted section, $D_1 - D_2$.
H_3 = drop of water surface in passing through the contraction, $D_1 - D_3$.
g = acceleration of gravity.
$V_1^2/2g$ = head due to velocity of water above contraction.
$V_2^2/2g$ = head due to velocity in most contracted section of channel.
$V_3^2/2g$ = head due to velocity of water downstream from contraction.

$$\alpha = \text{channel contraction ratio} = \frac{\text{cross-sectional area of obstruction}}{\text{cross-sectional area of channel}}.$$

$$\omega = \frac{\text{velocity head of water below contraction}}{\text{depth of flow below contraction}} = \frac{V_3^2/2g}{D_3}.$$

K = trestle-bent coefficient covering losses due to friction, impact, eddies, etc. The subscripts $D'A$, N, W, and R designate the D'Aubuisson, Nagler, Weisbach, and Rehbock formulas, respectively.
δ_o = trestle-bent coefficient in Rehbock general bridge-pier formula. (See equation 7, p. 5.)

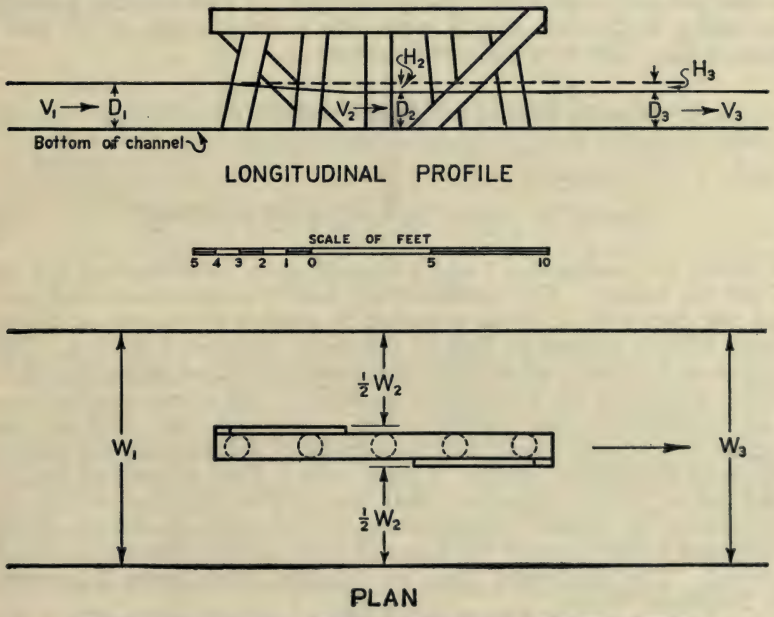


FIGURE 1.—Pile-trestle bent. See text for symbols used in pile-trestle formulas.

The real backwater height is shown in figure 1 as H_3. The surface drop in the contracted area, H_2, is sometimes erroneously called the backwater height.

D'Aubuisson (*2, pp. 188–191*) [4] probably first advanced the theory that the drop H_2 was merely the difference of the velocity heads for

[4] Italic numbers in parentheses refer to Literature Cited, p. 25.

points D_1 and D_2. The formula becomes

$$H_2 = Q^2/2g\ (1/K^2_{D'A} W_2^2 D_2^2 - 1/W_1^2 D_1^2) \tag{1}$$

in which $K_{D'A}$ is the D'Aubuisson coefficient.

The true backwater is not exactly represented by H_2, but ordinarily in practical field installations there will be little difference between H_2 and H_3 and hence little difference between D_2 and D_3. Therefore only the values of the D'Aubuisson coefficient using H_3 and D_3 are given. Transposing and rearranging the terms in equation 1, substituting V_1 for Q/W_1D_1 and H_3 and D_3 for H_2 and D_2, and solving for Q, equation 1 for practical use becomes

$$Q = K_{D'A} W_2 D_3 \sqrt{2gH_3 + V_1^2} \tag{2}$$

whence

$$K_{D'A} = \sqrt{Q^2/2gW_2^2D_3^2(H_3 + V_1^2/2g)} \tag{3}$$

Weisbach based his formula upon the assumption that the total discharge through the contracted section may be calculated as the sum of two quantities, one quantity consisting of the flow through a submerged orifice of width W_2 and height D_2, and another quantity consisting of the flow over a weir with a crest length of W_1 and a head of H_2. The formula then becomes

$$Q = K_W \sqrt{2g}\left[\frac{2}{3} W_1 (H_2 + V_1^2/2g)^{3/2} + W_2 D_2 (H_2 + V_1^2/2g)^{1/2}\right] \tag{3a}$$

Nagler's (*3*) formula is

$$Q = K_N W_2 \sqrt{2g}[D_3 - \theta(V_3^2/2g)]\sqrt{H_3 + \beta(V_1^2/2g)} \tag{4}$$

in which the coefficients θ and β depend upon conditions at the site of the pile trestle. The coefficient θ is merely a correction coefficient, and the factor $\theta(V_3^2/2g)$ is intended to correct D_3 to give a smaller depth of flow similar to that at the most contracted section. This coefficient has little effect upon the results obtained when the depth of the stream is an appreciable quantity. Its value was taken as 0.30 throughout this investigation. Although the formula was originally proposed merely for the purpose of determining the relative efficiency of different shapes of piers with a fixed amount of channel contraction, it was suggested that the coefficient β varies with the percentage of channel contraction, the amount of change in the coefficient being greatest for channel contractions between 5 and 30 percent. This coefficient may be obtained from figure 2 prepared by Professor Nagler.

Rehbock gives a formula applicable to only one condition of flow past the piers. He divides the flow into three classes as follows:

1. Ordinary or "steady" flow, in which the water passes the obstruction with very slight or no turbulence.
2. Intermediate flow, in which the water passing the obstruction displays a moderate degree of turbulence.
3. "Changed" flow, in which the water passing the obstruction becomes "completely" turbulent.

These three classes of flow are defined, according to Rehbock, by the following two equations.

$$\alpha_A = 1/(0.97 - 21\omega) - 0.13 \quad (5)$$

$$\alpha_B = 0.05 + (0.9 - 2.5\omega)^2 \quad (6)$$

The moving water is in the first class as long as the contraction ratio of the pier site is less than the limiting value in equation 5. When the value of α of the pier site under investigation lies between the values of α_A in formula 5 and α_B in formula 6, according to Rehbock the second condition of flow prevails. When the value of α of the pier site exceeds that given in equation 6, the third condition of flow exists.

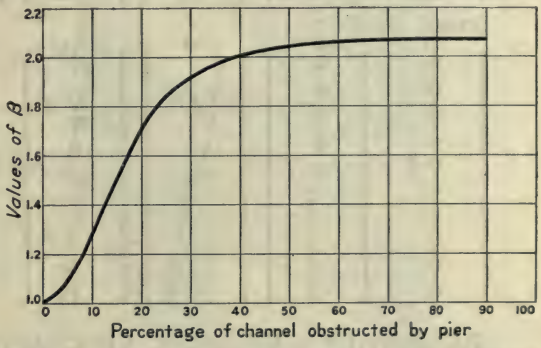


FIGURE 2.—Values of coefficient β to be used in Nagler bridge-pier formula.

The Rehbock equation (*1, pp. 122–128; 4, pp. 197–200; 5*) for computing the backwater height, H_3, for all pier shapes in a channel of rectangular cross section with ordinary or pure streaming flow, is as follows:

$$H_3 = [\delta_0 - \alpha(\delta_0 - 1)](0.4\alpha + \alpha^2 + 9\alpha^4)\ (1 + 2\omega)V_3^2/2g \quad (7)$$

A simple equation for bridge backwater is, according to Rehbock,

$$H_3 = K_R\alpha(V_3^2/2g) \quad (8)$$

It is probable that the D'Aubuisson, Weisbach, and Nagler formulas apply only to the first class of flow as defined by Rehbock.

Determinations of trestle-bent coefficients for the Weisbach formula were attempted, but the extremely discordant results indicated that this formula is theoretically unsound and the effort was abandoned.

There are many other backwater formulas mentioned in foreign publications on hydraulics. Of these, the most prominent (*6*) are: Dupuit, Eytelwein, Flamant, Freytag-D'Aubuisson, Gauthey, Heinemann, Hofmann, Lesbros, Mehmcke, Montanari, Navier, Rühlmann, Tolkmitt, Turazza, and Wex. For reasons of economy, pile-trestle coefficients were not determined for these formulas which are seldom mentioned in English texts on hydraulics.

SCOPE OF TESTS

Experiments were conducted on a full-size single-track 5-pile trestle bent (pl. 1, *A*) placed at angles of 0°, 5°, 10°, 15°, 20°, and 30° with the current (fig. 3). Tests were made also on a full-size double-track 10-pile trestle bent (pl. 1, *B*) with all piles in line with one another as well as with the current, to determine the effect of additional piling on the value of the coefficient. A double-track trestle

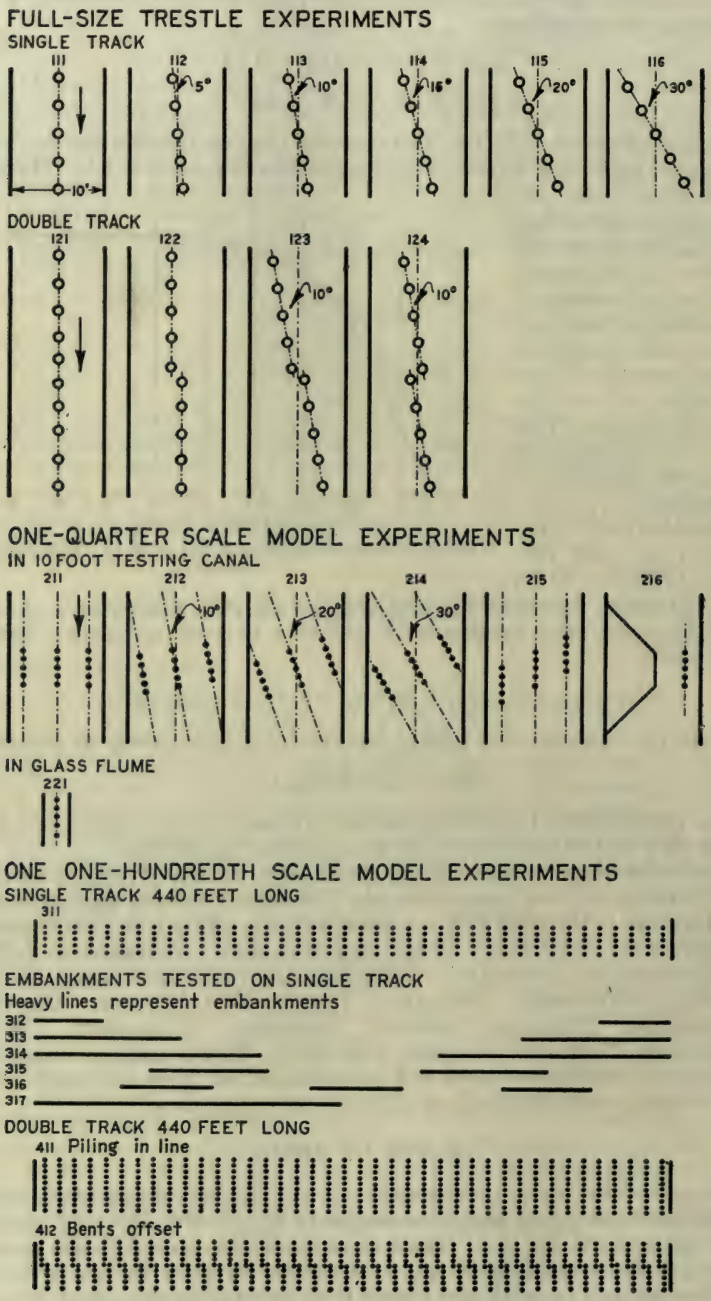
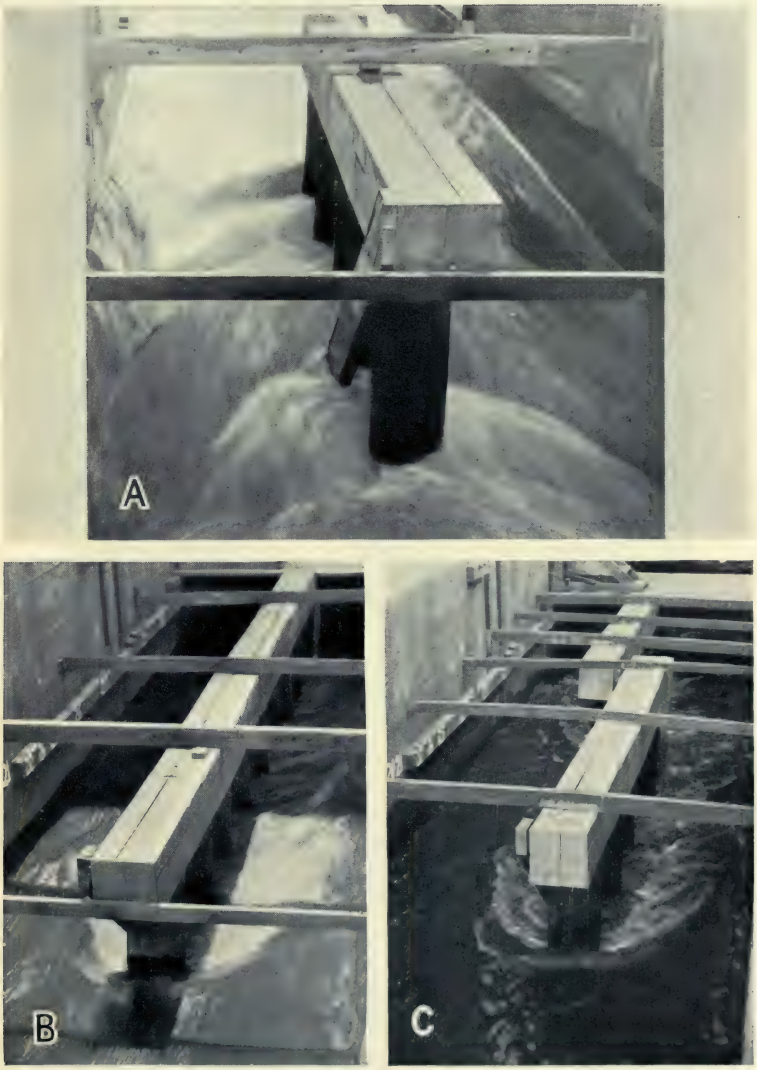
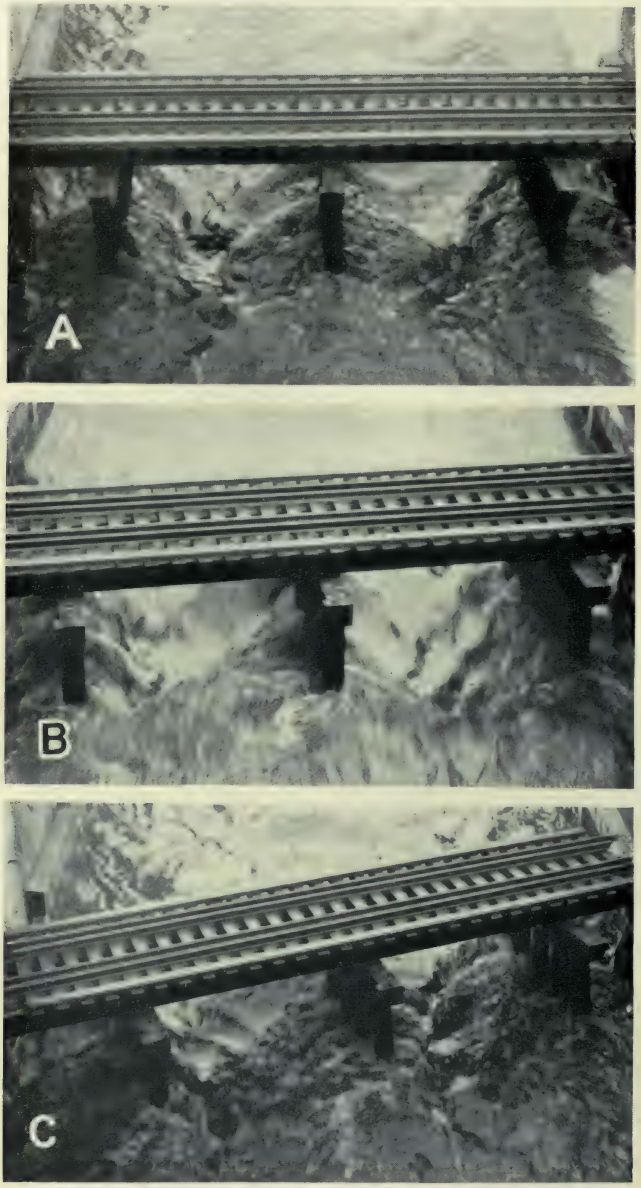


FIGURE 3.—Trestle set-ups tested.



FULL-SIZE PILE TRESTLES UNDER TEST.

A, Single-track 5-pile trestle bent in line with current; channel contraction, 16.2 percent. B, Double-track 10-pile trestle bent in line with current; channel contraction, 14 percent. C, Two single-track 5-pile trestle bents in line with current, bents offset; channel contraction 14 percent.

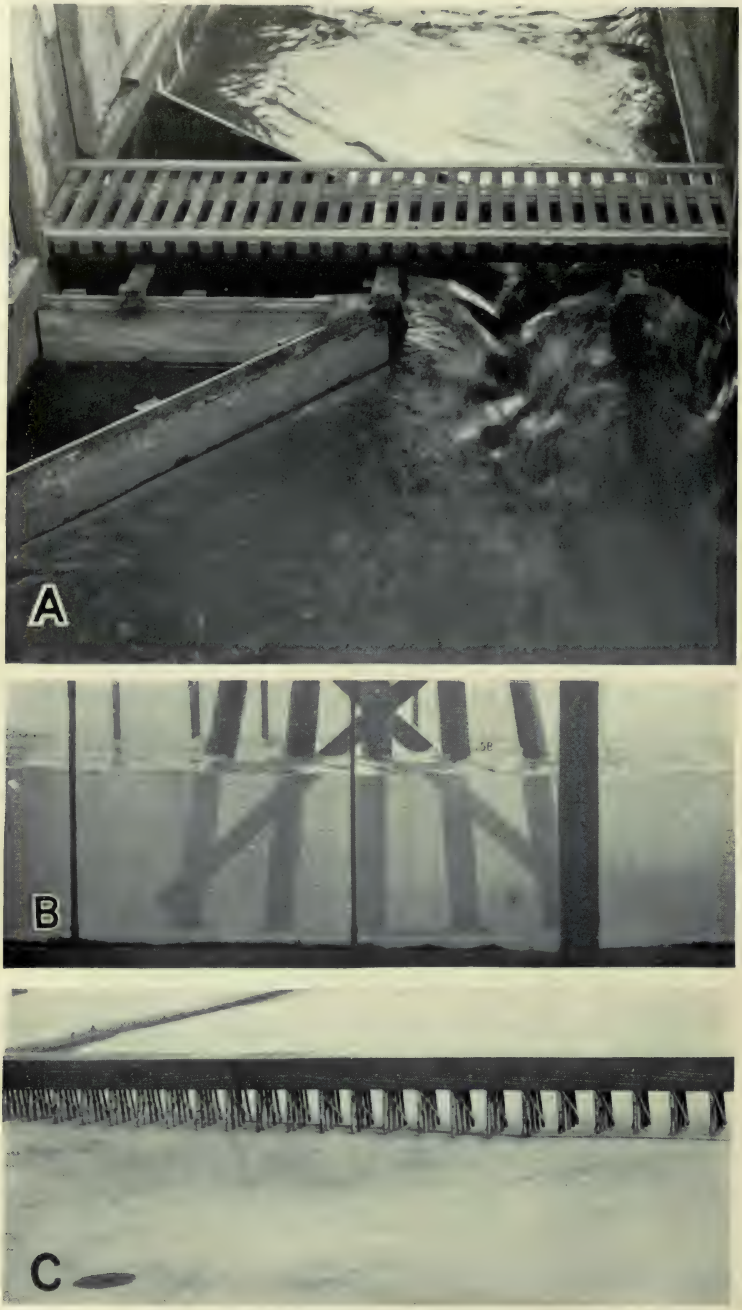


ONE-QUARTER SCALE MODEL OF 3-BENT SINGLE-TRACK PILE TRESTLE, 40 FEET LONG.

A, Bents in line with current, channel contraction, 12.5 percent. B, Bents at 10° angle with current, channel contraction taken as 12.5 percent. C, Bents at 20° angle with current, channel contraction taken as 12.5 percent.

ONE-QUARTER SCALE MODEL OF 3-BENT SINGLE-TRACK PILE TRESTLE, 40 FEET LONG.

A, Bents at 30° angle with current, channel contraction taken as 12.3 percent. B, Bents set in echelon in testing channel, angle of axis of deck with current, 60°; channel contraction as 12.3 percent.



TRESTLE MODELS UNDER TEST.

A, One-quarter scale model of a 20-foot single-track pile trestle. One end abutment and one bent in testing channel. Channel contraction taken as 56 percent. B, One-quarter scale model of a 5-pile trestle bent under test in glass-walled flume. C, One one-hundredth scale model of a single-track pile trestle 440 feet long.

bent consisting of two 5-pile bents, each offset from the other by the thickness of the piling and sway bracing, was tested with the pile lines parallel to the current and with the pile lines set at a 10° angle with the current. In the oblique position, tests were made with the bents offset first to the left and then to the right.

Tests were also conducted on a ¼-scale model representing a trestle 40 feet long with three 5-pile bents placed at angles of 0°, 10°, 20°, and 30° with the current, and also with the bents tested in echelon parallel to the current (pls. 2 and 3). In one test with this model the channel was obstructed as shown in plate 4, *A* to represent the effect of one trestle bent and one end abutment, the total channel contraction being 56 percent.

Check experiments on a ¼-scale model of a 5-pile trestle bent were run in the glass-walled flume of the laboratory, giving a channel contraction of 16 percent (pl. 4, *B*). The tests were conducted by first running a definite quantity of water through the unobstructed flume and taking readings of the water slope. Then the trestle bent was placed in the channel and the water-surface slope again read, to determine the amount of rise in the water surface upstream from the bent. Fourteen experiments were made in which the discharges ranged from 2.46 to 8.05 cubic feet per second, the depths of flow from 0.87 to 2.60 feet, and the velocities upstream from the bent from 1.09 to 1.94 feet per second.

To determine the effect of submergence upon the trestle coefficient, tests were run on the ¼-scale model with different degrees of submergence as follows: (1) With the water just touching the bottoms of the stringers; (2) with the upstream water surface at the top of the stringers; (3) with the upstream water surface to the top of the guard rail; (4) with the upstream water surface over the top of the guard rail.

To study the reliability of results obtained from tests on extremely small models, experiments were made on models constructed to a scale of 1 to 100, representing trestles 440 feet long with 5-pile bents (pl. 4, *C*). Experiments on this model were made with three quantities of flow and the following set-ups: (1) A single-track trestle, (2), a double-track trestle with bents in line, and (3), a double-track trestle with the bents offset. Other tests with the model of the 440-foot single-track trestle were made to investigate the obstruction to flow offered by an embankment with trestle openings, such as is commonly built to carry a railway or highway across a river valley subject to overflow at such height that the roadbed is above high water. Tests were run with various portions of the trestle blocked off to represent embankments of different lengths as shown for set-ups 312 to 317 in figure 3.

TEST PROCEDURE

Most of the experiments were run in the principal testing canal of the labratory, which is 312 feet long, 10 feet wide, and 10 feet deep. At its upstream end is an electrically operated head gate 10 feet wide by 10 feet deep. A calibrated weir of the suppressed type 10 feet long, for measuring flow in the canal, is located 60 feet downstream from the head gate. Numerous baffles were placed in the canal immediately below the head gate to obtain uniform velocity distribution as the water approached the weir, and a smooth flow over the

crest. Similar baffles were placed immediately downstream from the weir to prevent commotion of the water as it approached the pile trestles. An adjustable weir 6 feet high, located some 80 feet downstream from the center of the pile bent, was used to regulate the water level downstream from the trestle. This weir was hung on hinges and was adjusted by means of a block and tackle.

The loss of head caused by the trestles was measured by means of 37 piezometers on the wall of the canal. The piezometer openings through the wall were spaced throughout a distance of 69 feet, and were 4 inches above a level floor built in the bottom of the testing canal. Ten openings 2½ feet apart were made upstream from the trestle site, 15 openings 6 inches apart were made at the site, and 12 openings 2½ feet apart were made downstream from the site. The piezometers were 1-inch glass tubes 3 feet long attached to white-enameled gage staffs on the outside of the canal wall, and were connected to the wall openings by means of rubber tubing. The gage staffs, 3.3 feet long, were graduated to 0.02 foot, and the markings could be read to the nearest 0.01 foot with little chance of error.

Several staff gages also were set along both walls of the canal, the zeros of all being set even with the level floor constructed in the canal, to supplement the piezometer measurements in determining the depth of flow and the water-surface gradient above and below the pier as well as the depth in the contracted section along the trestle bent.

Tests in the 10-foot canal were conducted with quantities of flow ranging from 8 to 100 cubic feet per second and with depths of flow, D_3, from 0.8 foot to 3.2 feet, resulting in velocities past the trestles ranging from 0.6 foot to 5 feet per second. The height of trestle to bottom of stringer above the testing floor was 4.9 feet for the full-size bents and 3.6 feet for the ¼-scale models.

For the tests in the 10-foot canal, experiments were begun with a head of about 0.40 foot of water discharging over the measuring weir, followed by experiments with successive increases of about 0.05 foot in head on the weir, until the greatest possible quantity was obtained. Different depths of flow at the trestle site for each head on the weir were obtained by raising or lowering the adjustable weir.

With each quantity of flow two tests were run, in most cases, for each class of flow. To obtain the desired type of flow, in order to compare the Rehbock formula (equation 7) with the D'Aubuisson and Nagler formulas (equations 2 and 4), the procedure was as follows:

After the desired head on the weir was obtained, the observer first read the hook gage above the weir; then, knowing the quantity of flow he computed by means of equation 5 a depth which would give class 1 flow. The adjustable weir was regulated to obtain this depth. Readings were then taken on the various piezometers and staff gages, and a check reading on the weir hook gage to see if the quantity of flow had varied. Another test with a different depth but same class of flow was then run in the same manner. The depth for this test was also determined by means of equation 5. Then, without varying the quantity of flow, two tests at different depths in class 2 flow and two tests in class 3 flow were run. The range of depths for each class was determined by equations 5 and 6, and the desired variations in depth were obtained by means of the adjustable weir. With each increase in quantity of flow a similar series of tests was made.

Typical profiles of the water surface in the testing canal are shown in figures 5 and 6, for the 5-pile and 10-pile bents, respectively. The generally continuous loss of head through the length of the bent,

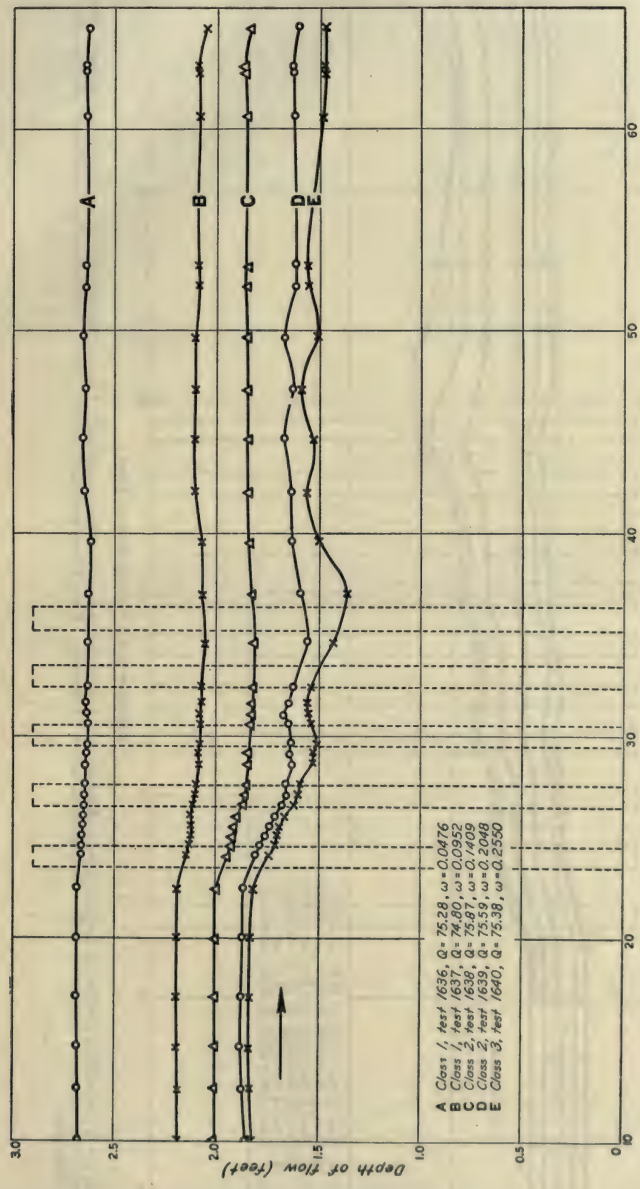


FIGURE 4.—Water-surface profiles in tests of full-size single-track 5-pile trestle bent parallel to current. Flow approximately 75 cubic feet per second; depth varied by means of adjustable weir. Channel contraction 16.2 percent. Each pile represented by two lines. Piezometer and staff-gage readings shown by symbols.

evidenced by the continuing decrease in depth, is very apparent and so is the partial recovery of velocity head immediately below the bent. The greater turbulence of the flow at higher velocities accompanying

the lesser depths is indicated by the irregularities of the profiles below the bridge site. The throttling effect of the obstruction is indicated

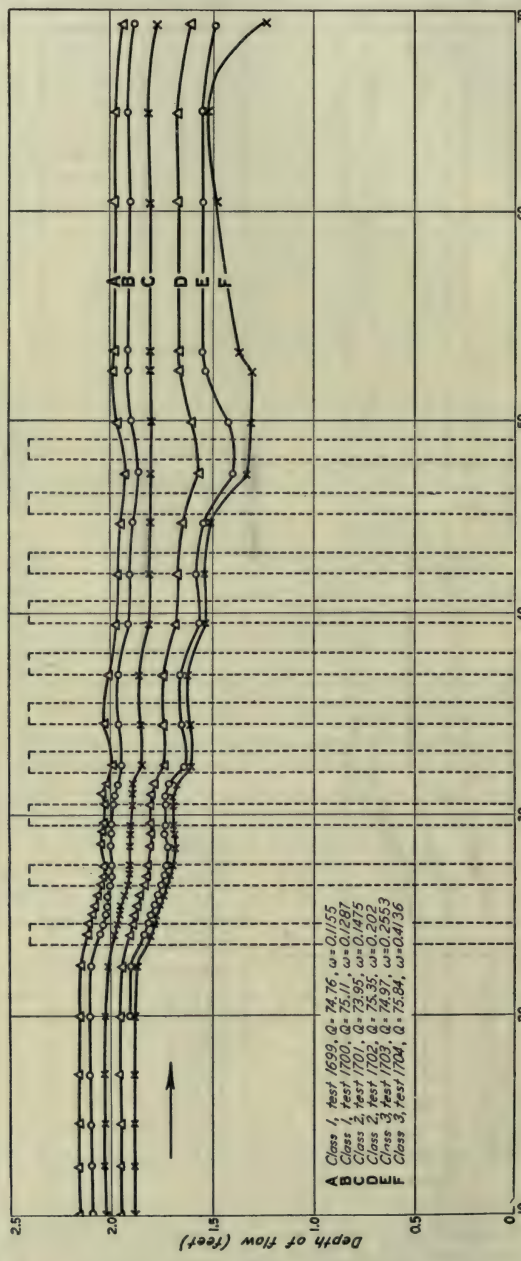


FIGURE 5.—Water-surface profiles in tests of full-size double-track 10-pile trestle bent parallel to current. Flow approximately 75 cubic feet per second; depth varied by means of adjustable weir. Channel contraction 14 percent. Each pile represented by two lines. Piezometer and staff-gage readings shown by symbols.

by the lesser changes in depth above than below the bent, with adjustment of the depth-control weir.

bent parallel
t, each bent
5-pile bents
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The pile-trestle coefficients for the D'Aubuisson, Nagler, and Rehbock formulas were computed by substituting the laboratory measurements of flow and surface drop and the other known factors in the equations 3, 4, 7, and 8. These coefficients were plotted against

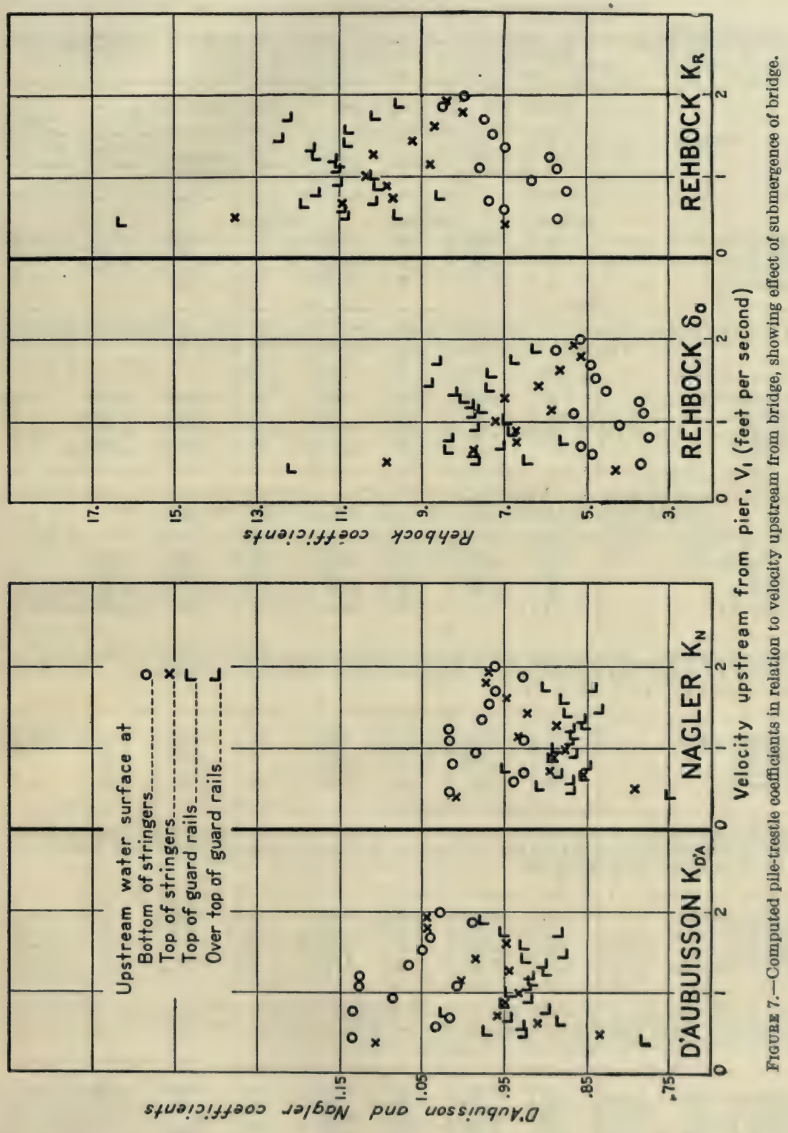

FIGURE 7.—Computed pile-trestle coefficients in relation to velocity upstream from bridge, showing effect of submergence of bridge.

the corresponding velocities, V_1, upstream from the trestle bent, and the results are shown in figures 6 and 7. Summaries of the coefficients for the full-size and ¼-scale-model set-ups are given in tables 1 and 2. Table 1 gives the coefficients which may be used in practical work.

The test results in table 2 are of only academic, theoretical interest and should not be used indiscriminately in practical work.

TABLE 1.—*Pile-trestle coefficients for bridge-pier formulas*

(For summary of recommended values, see table 9, p. 25)

Formula	Class 1 flow		Class 2 flow		Class 3 flow		Mean coefficient for classes 1 and 2 [1]	Mean coefficient for all 3 classes [1]
	Tests	Average coefficient	Tests	Average coefficient	Tests	Average coefficient		
FULL-SIZE SINGLE-TRACK TRESTLE, 0° ANGLE WITH CURRENT; CHANNEL CONTRACTION 16.2 PERCENT (pl. 1, *A*)								
	Number		*Number*		*Number*			
D'Aubuisson $K_{D'A}$	21	1.003	19	0.970	11	0.957	0.987	0.981
Nagler K_N	21	.885	19	.913	11	.943	.898	.908
Rehbock δ_0	21	5.03	19	6.41		[2]	5.68	
Rehbock K_R	21	3.02	19	4.51	11	5.34	3.72	4.12
FULL-SIZE DOUBLE-TRACK TRESTLE, 10 PILES IN LINE; 0° ANGLE WITH CURRENT; CHANNEL CONTRACTION 14.0 PERCENT (pl. 1, *B*)								
D'Aubuisson $K_{D'A}$	24	0.886	29	0.852	10	0.880	0.859	0.862
Nagler K_N	24	.817	29	.828	10	.873	.823	.831
Rehbock δ_0	24	11.84	29	12.70		[2]	12.31	
Rehbock K_R	24	7.28	29	8.41	10	8.32	7.90	7.96
FULL-SIZE DOUBLE-TRACK TRESTLE, DOWNSTREAM BENT OFFSET; 0° ANGLE WITH CURRENT; CHANNEL CONTRACTION 14 PERCENT (p.l 1, *C*)								
D'Aubuisson $K_{D'A}$	44	0.846	12	0.828	10	0.858	0.842	0.845
Nagler K_N	44	.782	12	.814	10	.928	.789	.810
Rehbock δ_0	44	12.95	12	14.25		[2]	13.23	
Rehbock K_R	44	7.31	12	9.55	10	9.93	7.79	8.11
ONE FOURTH-SCALE MODEL OF 40-FOOT SINGLE-TRACK TRESTLE; THREE 5-PILE BENTS IN TESTING CHANNEL; 0° ANGLE WITH CURRENT; CHANNEL CONTRACTION 12.5 PERCENT (pl. 2, *A*)								
D'Aubuisson $K_{D'A}$	28	0.978	27	0.972	11	0.971	0.975	0.974
Nagler K_N	28	.898	27	.933	11	.980	.915	.926
Rehbock δ_0	28	6.33	27	6.90		[2]	6.61	
Rehbock K_R	28	3.72	27	4.68	11	5.64	4.19	4.43
ONE FOURTH-SCALE MODEL OF 40-FOOT SINGLE-TRACK TRESTLE; THREE 5-PILE BENTS IN TESTING CHANNEL; 10° ANGLE WITH CURRENT; CHANNEL CONTRACTION 12.3 PERCENT (pl. 2, *B*)								
D'Aubuisson $K_{D'A}$	18	0.994	18	0.989	9	0.983	0.991	0.990
Nagler K_N	18	.914	18	.939	9	.983	.927	.938
Rehbock δ_0	18	5.48	18	5.93		[2]	5.71	
Rehbock K_R	18	3.25	18	3.93	9	5.14	3.59	3.90
ONE FOURTH-SCALE MODEL OF 40-FOOT SINGLE-TRACK TRESTLE; THREE 5-PILE BENTS IN TESTING CHANNEL; 20° ANGLE WITH CURRENT; CHANNEL CONTRACTION 12.3 PERCENT (pl. 2, *C*)								
D'Aubuisson $K_{D'A}$	18	0.952	14	0.960	9	0.958	0.956	0.956
Nagler K_N	18	.887	14	.923	9	.960	.903	.915
Rehbock δ_0	18	7.54	14	7.42		[2]	7.49	
Rehbock K_R	18	4.45	14	4.95	9	5.84	4.67	4.93

[1] Computed as the average of the individual determinations for all the tests, not as the average of the average determinations for the classes as shown in preceding columns.

[2] δ_0 was not computed for class 3 flow.

TABLE 1.—*Pile-trestle coefficients for bridge-pier formulas*—Continued

ONE FOURTH-SCALE MODEL OF 40-FOOT SINGLE-TRACK TRESTLE; THREE 5-PILE BENTS IN TESTING CHANNEL; 30° ANGLE WITH CURRENT; CHANNEL CONTRACTION 12.3 PERCENT (pl. 3, *A*)

Formula	Class 1 flow		Class 2 flow		Class 3 flow		Mean coefficient for classes 1 and 2	Mean coefficient for all 3 classes
	Tests	Average coefficient	Tests	Average coefficient	Tests	Average coefficient		
	Number		*Number*		*Number*			
D'Aubuisson $K_{D'A}$	21	0.920	9	0.929	9	0.932	0.923	0.925
Nagler K_N	21	.863	9	.906	9	.942	.876	.891
Rehbock δ_0	21	9.31	9	9.06		[2]	9.24	
Rehbock K_R	21	5.46	9	6.11	9	6.84	5.66	5.93

ONE FOURTH-SCALE MODEL OF 40-FOOT SINGLE-TRACK TRESTLE; THREE 5-PILE BENTS IN ECHELON IN TESTING CHANNEL, AXIS OF DECK AT ANGLE OF 60° WITH CURRENT; CHANNEL CONTRACTION 12.3 PERCENT pl. 3, *B*)

D'Aubuisson $K_{D'A}$	24	1.022	20	1.010	10	1.002	1.016	1.014
Nagler K_N	24	.934	20	.950	10	.997	.942	.952
Rehbock δ_0	24	4.23	20	5.09		[2]	4.62	
Rehbock K_R	24	2.53	20	3.39	10	4.55	2.92	3.22

ONE FOURTH-SCALE MODEL OF 20-FOOT SINGLE-TRACK TRESTLE; ONE END ABUTMENT AND ONE BENT IN TESTING CHANNEL; 0° ANGLE WITH CURRENT; CHANNEL CONTRACTION 56 PERCENT (pl. 4, *A*)

D'Aubuisson $K_{D'A}$	26	1.002	26	0.958	11	1.786	0.980	1.121
Nagler K_N	26	.925	26	.915	[3] 7	5.20	.920	1.428
Rehbock δ_0	26	5.42	26	6.02		[2]	5.72	
Rehbock K_R	26	7.70	26	8.92	11	2.73	8.31	7.33

[1] δ_0 was not computed for class 3 flow.
[3] Coefficients for 4 tests not included because very erratic.

TABLE 2.—*Computed coefficients for full-size pile trestles, bents placed at angle with current*

(Of academic interest only; for recommended values see table 7, p. 22)

SINGLE-TRACK TRESTLE; 5° ANGLE WITH CURRENT; CHANNEL CONTRACTION 14 PERCENT

Formula	Class 1 flow		Class 2 flow		Class 3 flow		Mean coefficient for classes 1 and 2 [1]	Mean coefficient for all 3 classes [1]
	Tests	Average coefficient	Tests	Average coefficient	Tests	Average coefficient		
	Number		*Number*		*Number*			
D'Aubuisson $K_{D'A}$	48	0.932	37	0.913	9	0.934	0.924	0.925
Nagler K_N	48	.843	37	.877	9	.929	.858	.865
Rehbock δ_0	48	8.27	37	9.35		[2]	8.74	
Rehbock K_R	48	4.74	37	6.38	9	6.48	5.45	5.55

SINGLE-TRACK TRESTLE; 10° ANGLE WITH CURRENT; CHANNEL CONTRACTION 14 PERCENT

D'Aubuisson $K_{D'A}$	64	0.904	19	0.874	13	0.887	0.987	0.896
Nagler K_N	64	.826	19	.848	13	.891	.831	.839
Rehbock δ_0	64	9.64	19	11.51		[2]	10.07	
Rehbock K_R	64	5.50	19	7.77	13	8.10	6.02	6.30

[1] Computed as the average of the individual determinations for all the tests, not as the average of the average determinations for the classes as shown in preceding columns.
[2] δ_0 was not computed for class 3 flow.

TABLE 2.—*Computed coefficients for full-size pile trestles, bents placed at angle with current*—Continued

SINGLE-TRACK TRESTLE; 15° ANGLE WITH CURRENT; CHANNEL CONTRACTION 14 PERCENT

Formula	Class 1 flow		Class 2 flow		Class 3 flow		Mean coefficient for classes 1 and 2	Mean coefficient for all 3 classes
	Tests	Average coefficient	Tests	Average coefficient	Tests	Average coefficient		
	Number		*Number*		*Number*			
D'Aubuisson $K_{D'A}$	61	0.868	19	0.834	11	0.871	0.860	0.861
Nagler K_N	61	.793	19	.805	11	.880	.796	.806
Rehbock δ_0	61	11.80	19	13.87		(2)	12.29	
Rehbock K_R	61	6.53	19	8.91	11	8.68	7.10	7.29

SINGLE-TRACK TRESTLE; 20° ANGLE WITH CURRENT; CHANNEL CONTRACTION 14 PERCENT

D'Aubuisson $K_{D'A}$	45	0.817	7	0.786	3	0.828	0.813	0.813
Nagler K_N	45	.754	7	.788	3	.842	.759	.763
Rehbock δ_0	45	15.18	7	16.82		(2)	15.40	
Rehbock K_R	45	8.30	7	11.58	3	10.28	8.74	8.82

SINGLE-TRACK TRESTLE; 30° ANGLE WITH CURRENT; CHANNEL CONTRACTION 14 PERCENT

D'Aubuisson $K_{D'A}$	55	0.789	11	0.767	(3)		0.785	
Nagler K_N	55	.729	11	.780	(3)		.737	
Rehbock δ_0	55	17.48	11	18.21	(3)		17.60	
Rehbock K_R	55	9.35	11	12.80	(3)		9.92	

DOUBLE-TRACK TRESTLE; DOWNSTREAM BENT OFFSET TO LEFT, LOOKING DOWNSTREAM; 10° COUNTER-CLOCKWISE ANGLE WITH CURRENT; CHANNEL CONTRACTION 14 PERCENT

D'Aubuisson $K_{D'A}$	49	0.768	2	0.748	8	0.777	0.768	0.769
Nagler K_N	49	.706	2	.762	8	.803	.708	.721
Rehbock δ_0	49	18.96	2	23.14		(2)	19.12	
Rehbock K_R	49	9.75	2	13.64	8	12.64	9.91	10.28

DOUBLE-TRACK TRESTLE; DOWNSTREAM BENT OFFSET TO RIGHT, LOOKING DOWNSTREAM; 10° COUNTER CLOCKWISE WITH CURRENT; CHANNEL CONTRACTION 14 PERCENT

D'Aubuisson $K_{D'A}$	36	0.802	10	0.793	8	0.830	0.800	0.804
Nagler K_N	36	.746	10	.780	8	.879	.753	.772
Rehbock δ_0	36	16.27	10	16.54		(2)	16.32	
Rehbock K_R	36	9.03	10	10.62	8	10.88	9.37	9.60

[2] δ_0 was not computed for class 3 flow.
[3] For this channel contraction there were no data in this class.

In figure 6 are plotted all the individual determinations that form the basis of table 1. Figure 7 shows the results of all tests to determine the effect of submergence upon the trestle coefficients. Table 3 shows results of experiments with the 1/100-scale model.

TABLE 3.—*Computations of pile-trestle coefficients for D'Aubuisson formula from tests on 1/100-scale models of trestles 440 feet long*

[The quantities stated in this table represent values in the prototype]

SINGLE-TRACK TRESTLE

Flow Q	Depth upstream D_1	Velocity upstream V_1	Backwater height H_3	D'Aubuisson coefficient $K_{D'A}$
Cubic feet per second	*Feet*	*Feet per second*	*Feet*	
6,800	5.27	2.95	0.07	0.960
14,000	7.97	3.99	.12	.972
15,300	9.85	3.53	.10	.943

DOUBLE-TRACK 10 PILES IN LINE

6,950	5.36	2.95	0.12	0.874
15,100	9.85	3.49	.12	.911
14,100	8.07	3.97	.17	.915

DOUBLE-TRACK OFFSET 5-PILE BENTS

6,700	5.26	2.90	0.10	0.897
14,050	8.10	3.94	.21	.876
15,200	9.87	3.50	.14	.887

In the computations, the amount of channel contraction was taken as the average diameter of the piles plus the thickness of the sway bracing, except when the deck of the trestle was submerged. For those tests in which the bent was placed at an angle with the current, the channel contraction was taken the same as for the same bent placed parallel to the current and the effect of building the trestle at an angle was thrown into the coefficient. The ¼-size model contracted the 10-foot channel 12.5 percent. The ¼-size model with the abutment (pl. 4, *A*) caused a channel contraction of 56 percent. The full-size single-track trestle with piles parallel to the current contracted the 10-foot channel 16.2 percent, and the full-size, double-track trestle with 10 piles in line contracted the channel 14 percent, the former being made of larger piles. With the full-size double-track trestle with offset 5-pile bents, the channel contraction was taken as 14 percent.

For the submergence tests, which were made on the ¼-scale model with one end abutment, the channel contraction was computed by taking the total wetted cross-sectional area of the trestle obstructing the flow of the water. For example, when the water was to the top of the stringers, the vertical area of the stringers and the cross-sectional area of the caps was added to the obstructing area of the piling, to get the amount of channel contraction.

Since the Rehbock formula (no. 7) was intended to apply only to class 1 flow as defined by equation 5, a fair comparison of this formula with the others can be made only with the tests belonging to class 1 flow. Hence, the tests were classified according to type of flow by applying equations 5 and 6.

Neither D'Aubuisson nor Nagler specified the kind of flow to which his formula applied. It is probable, however, that all three formulas are applicable only to class 1 flow. In this investigation

the D'Aubuisson and Nagler coefficients have been computed for classes 2 and 3 merely to determine the variation in coefficient with class of flow. It should be noted that except in some of the tests for class 3 flow with the ¼-scale model having the end abutment, the Nagler and D'Aubuisson formulas appear to apply very favorably to the experiments involving all classes of flow (fig. 6).

The Rehbock coefficient δ_0 was not computed for class 3 flow because this formula was intended to apply only to class 1 flow. The coefficients were computed for class 2 flow because cases of this class often occur, and there is not a great deal of difference between class 1 and class 2 flows. Class 3 flow seldom prevails at a bridge-pier site, except perhaps in mountain streams or at bridges having unusually large channel contractions.

The dispersion of the points in figures 6 and 7 is due to the fact that the drop or backwater caused by the trestle was often so small that unavoidable inexactness of measuring water-surface elevations caused appreciable inaccuracies in the computed coefficients. The average of the plotted points, however, should be thoroughly reliable. The rate of flow was controlled within 1 percent, hence the average coefficients in table 1 can be used with confidence in solving practical problems.

EFFECT ON COEFFICIENT OF BENTS PLACED IN LINE WITH THE CURRENT

SINGLE-TRACK TRESTLE

The full-size trestle bents in the 10-feet testing canal gave practically the same percentage of channel contraction as commonly exists in field installations. Including the thickness of the two sway braces, the average width of a trestle bent is about 1.65 feet. With such bents set on 11.75-foot centers the channel contraction is 14 percent, on 13-foot centers it is 12.7 percent, and on 13.75-foot centers the channel contraction is 11.2 percent. The full-size single-track bent used in these experiments had a channel contraction of 16 percent, but channel contractions caused by pile trestles range from 10 to 16 percent.

In making a comparison of coefficients obtained from tests on models of different sizes it is desirable to compare the coefficient for 1 or 2 formulas. In these comparisons the D'Aubuisson formula has been taken. Likewise the average coefficient for class 1 flow only has been taken for purposes of comparison.

It will be seen in table 1 that the D'Aubuisson coefficient for the full-size single-track trestle was 1.003. The D'Aubuisson coefficient for the ¼-scale model in the main testing canal, was 0.978. The average D'Aubuisson coefficient for 14 experiments on the ¼-scale model bent in the glass-walled flume was 1.00. The average D'Aubuisson coefficient for the 1/100-scale model trestle was 0.96 (table 3).

DOUBLE-TRACK TRESTLE

The D'Aubuisson coefficient for the full-size double-track trestle with the 10 piles in line was 0.866. The coefficient for the 1/100-scale model with the 10 piles in line varied from 0.874 to 0.915, an average being about 0.900

The D'Aubuisson coefficient for the full-size double-track trestle with the offset bents was 0.846. The coefficient for the 1/100-scale

model with the offset bents varied from 0.876 to 0.897, and average being about 0.887.

In comparing the coefficients for the double-track trestle with those for the single-track trestle it will be noted that the coefficients for the former are somewhat less than for the latter, showing that additional piles in line increase the resistance to the flow of the water. The values of the coefficients for the two full-size 5-pile trestle bents with the bents offset are also less than those for the full-size single-track trestle.

The obstruction offered by the double-track trestle with offset type of bents is a little greater than the type with the 10 piles in line in each bent.

The coefficient charts, figures 6 and 7, on which all of the coefficients obtained have been plotted, are of especial interest as they show the variation of the coefficient with velocity. If the coefficients had been plotted against the depth of flow, D_1, a similar but less coordinated vertical variation of the coefficients would have resulted.

It will be noted that the points on the D'Aubuisson and Nagler diagrams are bunched quite closely, particularly for those tests with class 1 and class 2 flows. The points on the Rehbock diagrams are quite scattered showing that Rehbock's formulas, insofar as the coefficients are concerned, are quite sensitive.

These charts show that generally within the range of the experiments the coefficients increase with an increase in discharge or velocity for D'Aubuisson and Nagler, contrary for Rehbock. The ideal bridge-pier or pile-trestle formula would be one in which the pier or trestle coefficient is a constant for all discharges.

EFFECT ON COEFFICIENT OF BENTS PLACED AT AN ANGLE WITH THE CURRENT

To obtain useful data on trestles placed at an angle with the current in which identical field conditions could be simulated, the ¼-scale model of a pile trestle 40 feet long was used. The results of these tests are given in table 1.

It will be noted that, with one exception, the D'Aubuisson and Nagler coefficients decrease with an increase in the angle the trestle bents make with the current. The D'Aubuisson and Nagler coefficients for the three ¼-scale model trestle bents set at a 10° angle with the current are slightly higher than those for the same trestle with the bents set in line with the current. This small increase in the coefficient, 1.6 percent, is logical since the beneficial effects of the partially echelon placement of the bents may more than offset the minor additional obstruction to flow offered by the 10° angle.

As the angle of the bent with the current increases beyond 10° the additional obstruction offered by the bent is not offset so much by the echelon effect of the bents, hence the coefficients decrease slightly with an increase in the amount of the angle.

Attention is called to the D'Aubuisson and Nagler coefficients for the three ¼-scale model trestle bents when set in echelon. These coefficients are some 5 percent greater than the coefficients for the three ¼-scale model bents set in line in the channel showing that bents set in echelon offer less obstruction to the flow than bents of a trestle crossing normal to the current.

The coefficients obtained from the tests on the full-size trestles placed at an angle with the current as shown in table 2 are not applicable to field installations since the actual obstruction caused by the full-size trestle when placed at an angle in the testing channel was much greater than that which would occur in a stream of greater width. These coefficients, however, have much theoretical and academic value and for that reason are included in this report.

EFFECT ON COEFFICIENT OF CONTRACTING STREAM CHANNEL BY ABUTMENTS

When a railway or highway embankment is built across a river valley subject to overflow, usually several waterway openings are planned at various intervals so that the flood waters can be discharged through the respective openings with comparatively little loss of head. The question naturally arises as to the method of computing channel contraction in such cases. If the gross width of the stream is considered to be no wider than that occupied by the trestle, then the contraction caused by the bents is small and usually lies between 11 and 14 percent. If the embankment is considered to obstruct part of the waterway, the percentage of contraction will be large. Investigations were made of the effect on the coefficient by the consideration of the embankment as part of the waterway contraction.

In the first series of experiments, an embankment, or more properly speaking, an abutment was added to the ¼-scale model of a single-track pile trestle 40 feet long as shown in plate 4, *A*. This set-up gave a contraction of 56 percent considering the width of the waterway as a whole. The D'Aubuisson coefficient $K_{D'A}$ for this set-up was 1.00, whereas the average coefficient for the same set-up without the end abutment was 0.98. It would appear from this set of tests that there will be comparatively little difference in the coefficient if different channel contractions are used.

The second series of experiments were made on the $\frac{1}{100}$-scale model of a single-track pile trestle 440 feet long in which portions of the trestle opening were blocked off so as to give the various percentages of channel contraction shown in set-ups nos. 312 to 317 in figure 3. The results of these tests are given in table 4.

TABLE 4.—*Variation of D'Aubuisson coefficient with contraction of waterway*

Set-up no.[1]	Contraction of 440-foot channel	End contractions	D'Aubuisson coefficient $K_{D'A}$	Set-up no.[1]	Contraction of 440-foot channel	End contractions	D'Aubuisson coefficient $K_{D'A}$
	Percent	*Number*			*Percent*	*Number*	
311	9	0	0.96	315	56	4	0.86
312	29	2	.94	316	48	5	.90
313	51	2	.95	317	46	1	.80
314	73	2	.94				

[1] See fig. 3.

It will be seen that the coefficients for the set-ups nos. 315, 316, and 317 are somewhat lower than the coefficients for the other set-ups. A duplicate test was run on set-up 315 and the value of the coefficient checked. Apparently there is little difference in the coefficients for set-ups 311 to 314, inclusive, even though the channel contraction for set-up 314 is two and one half times that for set-up 312.

It would appear from this that the amount of channel contraction does not have a great effect on the coefficient as long as critical velocity does not exist.

Disturbance of the symmetry of flow as in set-up 317 undoubtedly causes a decrease in the coefficient. The distribution of the flow through a series of multiple openings as in set-ups 315 and 316 reduces the coefficient by increasing the number of end contractions. However, when the openings have been made more numerous, the degree of contraction caused by the individual sections of the embankments may be decreased with a corresponding increase in the value of the coefficient as shown by set-up 316 in comparison with 315.

EFFECT ON COEFFICIENT OF SUBMERGENCE OF PILE TRESTLES

The experiments on the submergence of pile trestles were conducted on the ¼-scale model trestle with the end abutment. The area of obstruction to flow was computed by including the abutment and the bent and that portion of the stringers and guard rails which actually obstructed the flow of water. This additional area of resistance to flow was converted into width of equivalent obstruction so that the proper value of the effective width W_2 or the channel contraction factor could be used in the formulas.

A total of 47 experiments were made in which the deck of the trestle was submerged to varying depths. The coefficients obtained from these tests as illustrated in figure 7 show definitely that the Nagler and D'Aubuisson coefficients decrease as the amount of submergence increases, while the Rehbock coefficient δ_0 increases with an increase in submergence. The values of the coefficients for various degrees of submergence are shown in table 5.

TABLE 5.—*Summary of D'Aubuisson, Nagler, and Rehbock pile-trestle coefficients for trestles submerged varying amounts*

Water surface	Coefficient			Water surface	Coefficient		
	Nagler K_N	D'Aubuisson $K_{D'A}$	Rehbock δ_0		Nagler K_N	D'Aubuisson $K_{D'A}$	Rehbock δ_0
At bottom of stringers	0.97	1.06	4.53	At top of guard rails	0.88	0.93	7.56
At top of stringers	.91	.97	6.48	Over top of guard rails	.86	.91	7.90

USE OF DATA ILLUSTRATED BY EXAMPLES

These experiments have made available coefficients for use in hydraulic formulas for computing either the drop-down due to pile trestle bridges when the quantity is known or, knowing the drop-down, the quantity of water passing through the trestle opening. If either factor is definitely known, it is possible to compute the other factor with a reasonable degree of accuracy. This procedure can best be illustrated by practical examples.

Example 1: A stream discharging 6,600 cubic feet per second has a somewhat irregular section with a mean width of 206 feet and a mean depth of 8 feet. It is desired to compare the drop-down or backwater that would occur from the construction of the following types of obstruction in this channel.

(1) A single-track pile trestle.
(2) A double-track pile trestle, with 10 piles in line in each bent.
(3) A double-track pile trestle with bents offset but in line with the current.
(4) A single-track pile trestle with the bents set at an angle of 30° with the current.
(5) A single-track pile trestle with the axis of the deck at 60° with the current and the bents set in echelon.

For the purpose of illustrating the method of computation the backwater for set-up 1 will be given in full. The amounts of backwater computed for the other set-ups will be tabulated for purposes of comparison. The coefficients for set-ups 2 to 5 were taken from table 1 under class 1 flow.

With bents spaced 13 feet 9 inches center to center, there would be 14 bents obstructing the flow of the water in set-up 1. Including sway bracing, the average pile bent is about 1.65 feet wide. With 14 bents the total obstructed width would be 23.10 feet. The values of the known factors are as follows:

$Q = 6{,}600$ cubic feet per second
$W_1 = 206$ feet
$W_2 = 182.9$ feet
$D_3 = 8$ feet
$V_3 = 4.00$ feet per second
$\alpha = 23.1/206 = 11.2$ percent channel contraction
$\omega = \frac{V_3^2/2g}{D_3} = 0.2487/8 = 0.031$

Let H_3 be determined by substituting the above data in the Nagler formula (no. 4). Figure 2 shows $\beta = 1.31$. The test data give an average value of K_N as 0.90 and θ is taken as 0.30. In this formula the drop must first be assumed in order to obtain V_1. After the preliminary calculation, a check computation is made. Formula 4 shows $H_3 = 0.077$.

Substituting the above data in the D'Aubuisson formula and using $K_{D'A} = 0.99$ as determined from the test data gives $H_3 = 0.078$.

The Rehbock formula (no. 7) coefficient varies somewhat for the different scale models. Using the average coefficient obtained for the full-size trestle bent, or $\delta_0 = 5.68$, formula 7 gives $H_3 = 0.81$.

The backwater heights that would occur with the various trestle set-ups, as computed are stated in table 6.

TABLE 6.—*Backwater heights determined for example 1*

Trestle set-up	Backwater height computed by—		
	Nagler formula	D'Aubuisson formula	Rehbock formula
	Feet	*Feet*	*Feet*
1. Single-track pile trestle with axis of deck at right angles to current (pl. 1, *A*)	0.08	0.08	0.08
2. Double-track pile trestle with axis of deck at right angles to current, 10 piles in line in each bent (pl. 1, *B*)	.17	.18	.17
3. Double-track pile trestle with axis of deck at right angles to current, bents offset but in line with current (pl. 1, *C*)	.18	.21	.24
4. Single-track pile trestle with axis of deck at 60° angle with current and bents at 30° angle with current (pl. 3, *A*)	.12	.13	.13
5. Single-track pile trestle with axis of deck at 60° angle with current and bents in echelon (pl. 3, *B*)	.05	.06	.06

Example 2: A single-track pile-trestle bridge 825 feet long built across a river valley was subjected to a flood. At the crest of the flood, the drop-down in the water surface at the trestle was found to be 0.10 foot. The average depth of flow immediately downstream from the trestle was 6 feet. It is desired to compute the discharge through the trestle opening. Since the drop-down through the trestle opening was constant throughout its entire length, the discharge may be computed as a whole by considering the entire area of waterway.

With bents spaced 13 feet 9 inches center to center in a trestle opening 825 feet long there will be 59 bents obstructing the flow. Since a single bent including sway bracing will average 1.65 feet in width, the total obstructed area will be approximately 97.35 feet.

The values of the known factors are as follows:

$W_1 = 825.0$
$W_2 = 727.65$
$H_3 = 0.10$
$\alpha = 11.8$ percent
$D_3 = 6.0$
$g = 32.16$

The same coefficients given in the preceding set-up no. 1 will be used in these calculations.

The Nagler formula using $\theta = 0.30$ and $\beta = 1.32$ gives a discharge of 21,100 cubic feet per second.

The D'Aubuisson formula gives a discharge of 21,300 cubic feet per second.

The Rehbock formula gives a discharge of 21,000 cubic feet per second.

SUMMARY AND CONCLUSIONS

The investigation of the obstruction of pile-trestle bridges to the flow of water has brought out a number of facts which are of practical importance to all engineers, particularly those engaged in the solution of problems concerning the height of backwater caused by pile-trestle bridges.

The bridge-pier formulas most commonly used in this country are D'Aubuisson's:

$$Q = K_{D'A} W_2 D_3 \sqrt{2gH_3 + V_1^2} \tag{2}$$

Nagler's:

$$Q = K_N W^2 \sqrt{2g}[D_3 + \Theta(V_3^2/2g)]\sqrt{H_3 + \beta(V_1^2/2g)} \tag{4}$$

Rehbock's:

$$H_3 = [\delta_0 - \alpha(\delta_0 - 1)](0.4\alpha + \alpha^2 + 9\alpha^4)(1 + 2\omega)V_3^2/2g \tag{7}$$

Since all bridges made of pile trestles produce practically the same relatively small amounts of channel contraction, the question as to whether the pile-trestle coefficient is the same for various degrees of channel contraction does not arise. Hence the various trestle coefficients may be used in their respective bridge-pier formulas without correction for degree of channel contraction, in calculating the height of backwater caused by any pile-trestle bridge.

TABLE 7.—*Pile-trestle coefficients recommended for use in bridge-pier formulas*

Arrangement of trestle	Pile-trestle coefficients		
	D'Aubuisson $K_{D'A}$	Nagler K_N	Rehbock δ_0
Bents in line with current:			
Single-track 5-pile trestle bent	0.99	0.90	5.77
Double-track 10-pile trestle bent	.87	.82	11.9
2 single-track 5-pile bents offset	.85	.79	13.0
Bents at angle with current:			
Single-track 5-pile trestle bent at—			
10° angle	.99	.90	5.70
20° angle	.96	.89	7.50
30° angle	.92	.87	9.30

The coefficients given in table 7 are recommended for practical use in the respective formulas except in those rare cases in which the velocity is higher than the critical value (p. 5). The solution of practical problems of backwater caused by pile-trestle bridges involving velocities less than critical may be obtained by following the procedure shown on pages 19 to 21.

In using the coefficients it must be recognized, however, that the laboratory experiments which determined them covered a range of conditions much more limited than are met in practice. Where velocities and depths of flow are much greater than those obtained in the experiments, the results of computations should be applied with judgment. Of much value to hydraulic engineers would be actual measurements of backwater elevations caused by pile trestles in streams of considerable depth and velocity, together with the other data for determining the depth, velocity, and quantity of flow and the channel-contraction ratio caused by the trestle. Notation as to the amount and effect of debris lodged against the trestle would be an important item in such data.

The following conclusions have been drawn from the results of this investigation:

The amount of obstruction to flow offered by pile trestles may be determined through the use of the proper trestle coefficient in any of the approved formulas.

The detrimental effect of setting trestle bents at an angle with the current is less than might be expected. Little decrease in the coefficient, and hence in discharge, occurs unless the angle of the bent with the current exceeds 10°.

The discharge coefficient for trestle bents set at a 30° angle with the current is about 4 percent less than that for bents parallel to the current.

Some beneficial effect can be obtained by setting trestle bents in echelon if a roadway must cross a stream at an angle.

If the axis of the roadway is at a 60° angle with the current and the bents are set in echelon, the Nagler and D'Aubuisson coefficients are about 5 percent greater than those for the same trestle crossing the stream at right angles to the current and the bents parallel to the current.

When water of the given depths and quantity flows through the trestle set-ups outlined in example 1 (p. 19) the following conclusions may be drawn:

A double-track pile trestle with 10 piles in line in each bent produces approximately twice the amount of back water that is caused by a single-track pile trestle constructed of bents with 5 piles in line.

A double-track trestle with the bents offset offers somewhat greater obstruction than a double-track trestle with 10 piles in line.

A single-track pile trestle with the bents set at a 30° angle with the current causes from 50 to 70 percent greater depth of backwater than a single-track pile trestle crossing the channel at right angles with the bents parallel to the current.

A single-track pile trestle with the axis of the deck at 60° with the current and the bents set in echelon parallel to the current causes from 53 to 60 percent less backwater than a single-track trestle with the same deck angle but with the bents set at a 30° angle with the current.

A single-track pile trestle with the axis of the deck at 60° with the current and the bents set in echelon parallel to the current gives from 27 to 40 percent less backwater than a single-track pile trestle crossing the channel at a right angle with the bents parallel to the current.

APPENDIX

ANALYSIS OF D'AUBUISSON FORMULA

The D'Aubuisson formula (2) may be written in the following form:

$$Q/W_2D_3\sqrt{2g}=K_{D'A}(H_3+V_1^2/2g)^x$$

This is the equation of a straight line when plotted on logarithmic coordinates. With the expression $H_3+V_1^2/2g$ plotted as abscissas and $Q/W_2D_3\sqrt{2g}$ plotted as ordinates, the exponent "x" is the slope of the line and the coefficient $K_{D'A}$ is the point at which the line intersects the vertical unity axis. In his formula, D'Aubuisson uses the value of 0.5 for the exponent "x." In order to check the correctness of this value for pile trestles, points for class 1 flow were plotted on logarithmic paper using the above equation. The straight line defined by the majority of the points, determined by inspection, was drawn and its slope and intercept found graphically. These values are given in columns 2 and 3 of table 8. Next, a line with a slope of 0.5 was drawn in the same manner and its intercept determined, these values being given in column 3, of table 6. Column 5 is taken from tables 1 and 2, and gives the corresponding values of the coefficient determined by computation, and is included here to facilitate comparison with columns 2 and 3. The values of the exponent "x", are so nearly 0.5 that it is not desirable to depart from this value for pile trestles, although for some solid piers with certain shapes of noses and tails, tested previously,[5] an exponent of 0.6 was found more suitable.

TABLE 8.—*Comparison of D'Aubuisson coefficients for pile trestles determined by graphical methods with coefficients obtained from the formula (class 1 flow only)*

ONE-QUARTER SCALE TRESTLE MODELS

Test set-up	Exponent and coefficient as determined graphically		Coefficient determined graphically if x=0.50 $K_{D'A}$	Computed coefficients (tables 1 and 2) $K_{D'A}$
	x	$K_{D'A}$		
Three 5-pile bents in testing channel; 0° angle with current	0.531	1.09	1.00	0.978
1 bent and 1 end-abutment in testing channel	.478	.96	1.00	1.002

[5] Unpublished data.

TABLE 8.—*Comparison of D'Aubuisson coefficients for pile trestles determined by graphical methods with coefficients obtained from the formula*—Continued

FULL-SIZE SINGLE-TRACK TRESTLE BENTS

Test set-up	Exponent and coefficient as determined graphically		Coefficient determined graphically if x=0.50 $K_D'_A$	Computed coefficients (tables 1 and 2) $K_D'_A$
	x	$K_D'_A$		
0° angle with current	0.521	1.05	1.01	1.003
5° angle with current	.557	1.03	.940	.932
10° angle with current	.538	.97	.930	.904
15° angle with current	.550	.95	.870	.868
20° angle with current	.500	.82	.820	.817
30° angle with current	.500	.79	.790	.789
FULL-SIZE DOUBLE-TRACK TRESTLE BENTS				
10 piles in line; 0° angle with current	0.575	0.97	0.89	0.866
5 piles offset; 0° angle with current	.516	1.13	1.08	.846
Downstream bent offset to left, 10° angle	.540	1.07	.95	.768
Downstream bent offset to right, 10° angle	.529	1.10	1.05	.802

COMPARATIVE ACCURACY OF THE D'AUBUISSON, NAGLER, AND REHBOCK FORMULAS

The method of classifying flow was checked by plotting the data on logarithmic charts. All tests in class 1 flow as defined by Rehbock's empirical formula 5 were plotted using the thickness of the bent as the channel contraction regardless of the angle the bent made with the current. Some of these points would have fallen in classes 2 and 3 if the projected area of the bent had been used as the channel contraction for the purpose of classifying flow. For identification purposes, these latter points were distinguished by certain symbols. If the points tended to form three separate groups the method of classification followed would have been shown to be erroneous, but as all the points tended to group about the same straight line it is reasonable to assume that the method of classification used was proper.

If the average coefficients for class 1 flow as shown in table 1 are used with the observed test data in the respective formulas and new backwater values computed the relative accuracy of the various formulas, insofar as the test data are concerned, may be determined by comparing the computed amounts of backwater with the observed amounts of backwater. This method, however, does not include any consideration of the simplicity of a formula in obtaining the desired data.

Of the many statistical methods which may be used in making a comparison of the various backwater formulas, the following three were employed. In the first method, the summation of the deviations or the differences between the computed and observed backwaters, regardless of sign, was determined for each formula and this summation divided by the number of tests gave the mean deviation. By this method, the formula having the smallest mean deviation most nearly fits the experimental data. In the second method of comparison, the summation of the squares of the deviations was determined for each formula, and this summation divided by the number of tests gave the mean of the squares of the deviations. The mean-square deviation or error might be obtained by extracting the square root of the mean of the squares of the deviations. By the third method of comparison, the summation of the percentages obtained by dividing the individual deviations by the corresponding observed backwater heights was obtained, and this summation was divided by the number of tests. The result was the average percentage deviation or error in computation by the formula under consideration. The differences between the formulas are not at all significant, as may be seen in table 9.

TABLE 9.—*Difference between observed backwaters and those computed by different formulas*

Formula	Mean deviation from observed H_3		
	Average of deviations	Average of squares of deviations	Average of percentage deviations
	Foot	*Square foot*	*Percent*
Nagler	0.00966	0.000188	15.5
D'Aubuisson	.0104	.000189	17.4
Rehbock	.0119	.000257	19.9

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CERCOSPORELLA FOOT ROT OF WINTER CEREALS

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[The Bureau of Plant Industry in cooperation with the Oregon, Washington, and Idaho Agricultural Experiment Stations]

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INTRODUCTION

Cercosporella foot rot of winter cereals, also known as the Columbia Basin foot rot, is a serious economic problem in certain prairie sections of Washington, Oregon, and Idaho (*28*).[2] In a recent report (*29*) it was shown that the disease is caused by *Cercosporella herpotrichoides* Fron. It is the purpose of this bulletin to summarize the results of investigations on this disease.

REVIEW OF LITERATURE

Cercosporella herpotrichoides Fron was named in 1912 from material gathered in northern France 3 years previously. Fron (*13*) considered that the fungus was the conidial stage of *Leptosphaeria herpotrichoides* DeNot. In 1914 Foëx (*5*) found conidia of *C. herpotrichoides* on wheat. In referring to Fron's belief that *C. herpotrichoides*

[1] The writers are indebted to A. G. Johnson, principal pathologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, and to H. P. Barss, formerly plant pathologist in charge of botany and plant pathology, Oregon Agricultural Experiment Station, for criticism of the manuscript. The field and station staffs of plant pathology, botany, and agronomy of the three experiment stations have rendered invaluable aid. Acknowledgments are due W. S. Nelson, of the Wasco County Chamber of Commerce, The Dalles, Oreg., for aid in the investigations.

[2] Italic numbers in parentheses refer to Literature Cited, p. 23.

was connected with *L. herpotrichoides*, Foëx noted that this is not definitely known.

In 1919 Foëx (*6*) reported finding *Cercosporella herpotrichoides* at the end of March on wheat sown August 9 of the previous year and also on the sheaths of culms placed in the ground, as well as in stubble on which *Leptosphaeria herpotrichoides* and *Ophiobolus herpotrichus* (Fr.) Sacc. had been produced. He suggested that if *C. herpotrichoides* is the conidial stage of *L. herpotrichoides*, it must, without doubt, play a role in the propagation of the fungus, but again he pointed out that it had not been possible to establish the connection between these two forms. Foëx also reported that *C. herpotrichoides* was sometimes found on wheat culms that had produced perithecia of *L. herpotrichoides*, *O. graminis* Sacc., and *O. herpotrichus*, but he did not consider this association as proof of connection of this conidial form with any of these ascigerous forms.

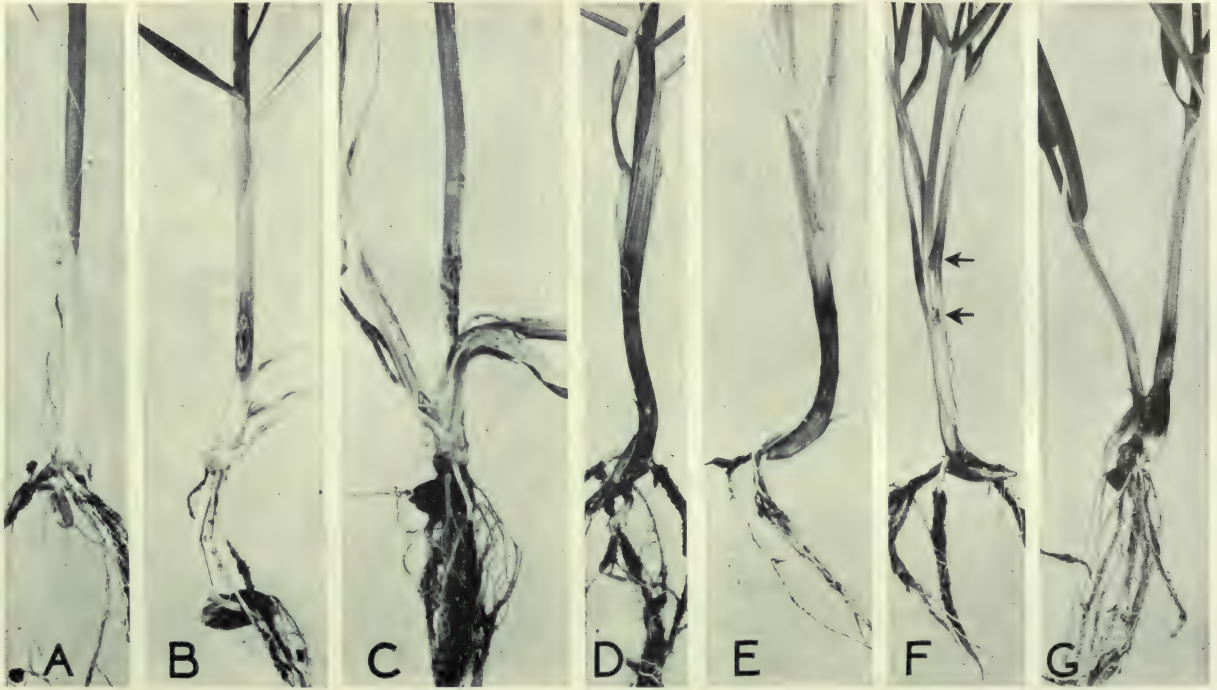
From 1919 to 1924 Heald (*18*) consistently isolated a sterile fungus, now known to be *Cercosporella herpotrichoides*, several Fusaria, and a fungus referred to as *Wojnowicia graminis* (McAlp.) Sacc. and D. Sacc. from diseased culms of wheat grown near Spokane, Wash. Preliminary experiments conducted at Pullman, Wash., indicated that none of these fungi was pathogenic on wheat. The foot rot studied by Dana (*2*) was different from the one caused by *C. herpotrichoides*, as his studies were confined to western Washington, where this latter disease has thus far not been found.

In 1925 some of the late-season symptoms were mentioned by McKinney (*23*), who briefly presented the results of the early cooperative experiments in the Pacific Northwest.

Nearly 10 years after Heald and his coworkers first began to isolate the "sterile fungus", later shown to be *Cercosporella herpotrichoides*, Foëx and Rosella (*7, 8*) isolated a similar organism in France which they termed "champignon x" (fungus x). They were able to induce the disease with this organism. They also found spores of *C. herpotrichoides* on artificially inoculated plants (*9, 10*), but were unable to obtain the spores of the fungus in pure cultures. In 1931 (*11*) they stated that the fungus x apparently was the one responsible for most of the really serious cases of foot rot found in the preceding few years in the Departments of Seine-et-Oise and Eure-et-Loir, France. In 1931 Kerleroux (*20*) found that the fungus x attacked wheat plants both in the fall and spring, but more severely in the spring following a severe winter.

In 1929 and again in 1930 the senior writer obtained spores of *Cercosporella herpotrichoides* in pure culture from mycelium of the long-known but supposedly sterile fungus isolated from wheat culms collected in Oregon and Washington (*29*). Until he obtained what he at first assumed were *Cercospora* spores in the early fall of 1929, the original articles of Fron and Foëx had not been reviewed. While the article by the senior writer (*29*) was being prepared for publication the article of Foëx and Rosella (*9*) came to hand, and through the kindness of Doctor Foëx the macroscopic identity of the fungus in the United States and of that from France was determined. Since that date, typical spores of *C. herpotrichoides* Fron were obtained in pure culture transfers of an isolation of the so-called "fungus x" furnished to the senior writer. The pathogenicity of the *C. herpotrichoides* from the Columbia Basin was proved (*29*).

A, Eye-spot lesions on leaf sheaths from winter-wheat plants, High Prairie, Wash., April 3, 1930. ×2. *B*, Culm, with the sheaths pulled back, showing young lesion. ×2. *C*, Basal portions of old diseased wheat culms with sheaths removed. ×½. *D*, Young plants of Hybrid 128 club wheat affected with cercosporella foot rot, High Prairie, Wash., Mar. 24, 1931 (sown Sept. 1), showing start of infection at the ground line. ×⅗. *E*, The disease advanced farther than in *D*, showing injury from ground line down to crown. ×⅗.



BASAL PORTIONS OF PLANTS INOCULATED AT SEEDING TIME WITH PURE CULTURES OF CERCOSPORELLA HERPOTRICHOIDES AND KEPT IN A COOL GREENHOUSE.

A, Hybrid 128, uninoculated check. ×⅜. *B*, Hybrid 143 wheat 3 months after inoculation, showing eye-spot lesion. ×1. *C*, Same as *A* but with outer leaf sheaths stripped back, showing stromata of the fungus between the sheaths. ×1. *D*, Alstroum spelt, a very susceptible host, with extensive lesion on base of culm. ×⅜. *E*, Alaska barley, showing long but superficial lesion at base of culm. ×⅜. *F*, Einkorn, a very resistant host, showing very small lesions at ground line as indicated by arrows. ×⅜. *G*, Lesions on Hybrid 128 wheat. ×⅜.

SYMPTOMS OF THE DISEASE

Cercosporella herpotrichoides attacks chiefly the basal leaf sheaths and internodal tissues of the culms at or near the soil line. The fungus does not attack underground portions of the host. In some cases brace roots are invaded for a short distance where they come in contact with infested soil, and occasionally the tissues of the basal nodes also are penetrated.

Unless otherwise stated, the symptoms of the disease were observed on susceptible winter wheat (*Triticum vulgare* Vill.).[3]

SYMPTOMS IN EARLY SEASON

In the Pacific Northwest most of the infection begins in late February or early to mid-March, depending on the season. The first lesions become evident on the outer leaf sheaths as pin-point, water-soaked areas. These enlarge vertically and when fully developed are 1 to 2 centimeters long and 3 to 6 millimeters wide. The lesions are elliptical and have a tendency to become ovate after the expanding lesion meets obstructing nodal tissue. In March and April the lesions when well developed are fawn colored to nearly white and are bordered by an amber-brown[4] to chestnut-colored area (pl. 1, *A*). In later stages, early May to harvest time, secondary fungi and the gradual nonparasitic necrosis of the sheath obscure the clear-cut outlines of these outer lesions. Foëx and Rosella (*8*) term the fully developed lesions "taches ocellées" (eye-spot lesions).

The fungus is able to penetrate into deeper tissue either directly from one sheath to the next (pl. 1, *D* and *E*) or through the rupture of the sheaths by crown roots.

In the early-season infections a visible dark-olive to black stroma develops at the ground line between each leaf sheath and over the eye-spot lesions. This stroma gives the diseased host parts a charred appearance (pls. 1 and 2). Various stages in the development of the disease on artificially inoculated plants are illustrated in plate 2.

The weaker tillers of a plant are the first to be attacked, and these become sources of infection for the stronger ones. The fungus reduces the number of tillers, and while the less-crowded survivors partially refill the vacancies a seriously diseased field has a distinctly thinner stand after heading time.

SYMPTOMS IN LATE SEASON

The disease usually is most conspicuous near the end of the growing season of the host. Diseased plants are characterized by an excessive number of dead, brown tillers. The culms are affected in the first or second internode with lesions that extend from the ground line upward for 1 or 2 inches (pl. 1, *B*, *C*). The culm lesions vary from almost white (ivory yellow) to black, depending on the extent of development of the stroma. The culm tissue in the lesions is firm and brittle, slightly to distinctly collapsed on one side of the stem, or later the lesion completely girdles the culm and is bordered by discolored to amber-brown, sometimes (later) xanthine-orange areas.

[3] According to the rules of botanical nomenclature the name of this species is *T. aestivum* L., but as *T. vulgare* is in general use among agronomists and cereal pathologists and geneticists, the writers give preference to that form.

[4] RIDGWAY, R. COLOR STANDARDS AND COLOR NOMENCLATURE. 43 p., illus. Washington, D.C. 1912.

The fungus spreads faster in the parenchyma in the lumen region than it does nearer the outer surface of the culm. During moist weather in late season (June to July) the lumen of a large percentage of the diseased culms becomes filled with wefts of smoke-gray mycelium.

After the heads become heavy with grain the diseased culms buckle at the lesions and fall. The percentage of culms that fall varies according to the variety, the succulence of the culm, the severity of infection, and the occurrence of beating storms. Inasmuch as the period of falling extends over a considerable time during which the wind may blow from various directions, the grain becomes badly crisscrossed as it falls, and it is difficult and often impossible to harvest it (pl. 3). If driving rains occur near harvest time, the grain in heavily infested fields lodges very badly.

In the sections of the cercosporella foot-rot area where grain grows very tall, as in the Grande Ronde Valley of Oregon, lodging often occurs in wheat not injured by foot rot. Whereas the diseased culms buckle at the point of injury, the nonparasitized lodged culms usually bend in an arc that involves several of the lower internodes. In some cases where the ground is very soft following rains, the nonparasitized lodged plants are partly uprooted. Wheat culms attacked by *Cercosporella herpotrichoides* are frequently weakened to a point where they scarcely react to geotropism, whereas the heads of nonparasitized lodged culms usually become at least partly erect by growing upright at the nodes.

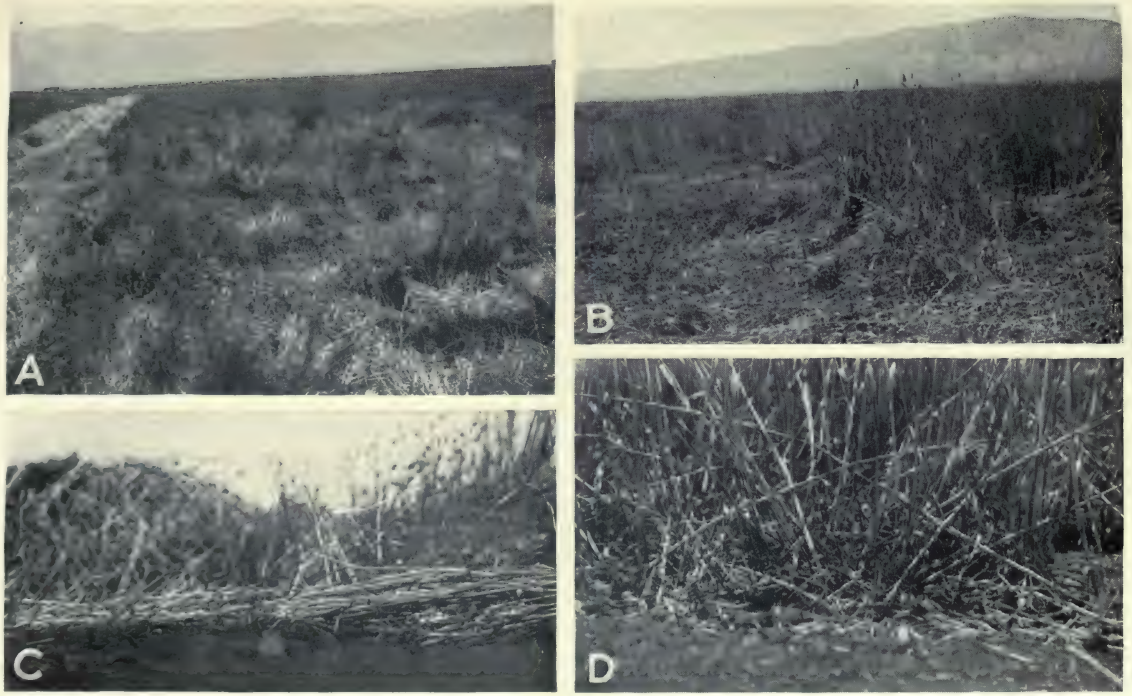
In severe cases, when infection starts early and continues throughout the rainy season, the culms may become stunted and fail to head. Saprophytic sooty molds may overrun entire plants, causing them to become fragile and to ripen prematurely.

The appearance of the diseased plants, as described above, contrasts rather sharply with that of plants affected with "take-all", a disease caused by *Ophiobolus graminis*.

Ophiobolus graminis attacks the underground portions of the wheat plants, progresses upward, and, as a rule, does not attack the inner leaf sheaths. The black lesions in take-all have a dark neutral-gray appearance when viewed through the thin sheaths, whereas those on cercosporella-infected plants appear charred.

SYMPTOMS FROM SECONDARY INFECTIONS

The growing season in the Grande Ronde Valley of Oregon starts later in the spring than it does in the Columbia Gorge area of Oregon and Washington, and the rainy season also is considerably more protracted in the former area. As a result of these conditions, new infections, which are in part secondary from spores, begin developing in the Grande Ronde Valley at any time up until harvest. These later lesions, which also have the eye-spot appearance, have vague to sometimes dark-brown borders. The primary stromatic tissue begins to form at the point where the fungus first enters the sheath and underlying culm. Since the fungus may become arrested by dry weather, it is not uncommon to find elliptical lesions with scarcely any bordering of discolored tissue and no trace of stromatic mycelia except possibly a pin-point spot at the point of invasion. If the culm ripens early because of dry weather, these lesions become somewhat enlarged through necrosis, resembling sun scald.



FIELD SYMPTOMS OF THE CERCOSPORELLA FOOT ROT OF WHEAT IN THE GRANDE RONDE VALLEY OF OREGON, 1928.

A, General view of a field of Hybrid 128 wheat showing the culms fallen in many directions, causing a tangled condition that increases the expense of harvest. *B*, View of badly fallen wheat, showing considerable areas flat; a few slightly diseased plants are still standing. *C*, Detailed view of culms at ground line showing how closely appressed the fallen grain frequently is. This makes harvest difficult and slows up the ripening process. *D*, Detailed view showing the beginning of falling.

SYMPTOMS ON WINTER BARLEY

Cercosporella foot rot appears on barley (*Hordeum vulgare* L.) somewhat later in the spring than it does on wheat. The fungus attacks the inner portion of the barley culms far more readily than it does the hard outer portions. Also, the fungus forms less stromatic tissue on barley than on wheat, and there is less collapse of tissues in the lesions near maturity. Secondary fungi are especially confusing in this host. In general, there is less buckling of the culms in barley than in wheat.

GEOGRAPHIC DISTRIBUTION AND ECONOMIC IMPORTANCE

In the United States, cercosporella foot rot occurs in three main areas, all within Washington, Oregon, and Idaho, as follows: The rolling prairie country lying at an elevation above 1,500 feet, adjacent to the Columbia Gorge in Wasco County, Oreg., and Klickitat County, Wash.; the relatively level Grande Ronde Valley, in eastern Oregon, surrounded by the Blue Mountains, and the adjacent prairie lands in Oregon and Washington; and in the Spokane Valley on gravelly prairie soil in Washington and Idaho and on fine sandy loam on adjacent prairie lands in Washington.

The counties in Washington, Oregon, and Idaho where cercosporella foot rot has been found, and the estimated reduction in yield of wheat, in bushels, are shown in table 1. The injury varies greatly from season to season. The seasonal severity of the disease was as follows: 1928, very severe; 1929, slight; 1930, moderate; 1931, moderate; and 1932, severe. In spite of the severity of the disease development in 1932, the total losses are noted as less or no greater than in either of the 2 preceding years. There are two reasons for this: (1) Many farmers discontinued the growing of wheat in the fall of 1931 because of the previous losses sustained and because of low prices, and (2) many farmers who continued to grow wheat used relatively resistant varieties and followed practices that reduced the development of the disease.

TABLE 1.—*Estimated reduction in yield of wheat caused by cercosporella foot rot in certain counties of Washington, Oregon, and Idaho, 1928–32*[1]

State and county	Estimated reductions in yield				
	1928	1929	1930	1931	1932
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Washington:					
Klickitat	6,500	1,500	1,500	2,500	2,500
Spokane	16,000	2,000	4,000	11,000	10,500
Walla Walla	(2)			1,000	1,000
Oregon:					
Umatilla	(2)			(2)	(2)
Union	60,000	10,000	12,000	4,000	3,000
Wasco	12,000	4,000	3,500	2,500	2,000
Idaho:					
Kootenai			(2)	1,000	2,500
Total	94,500	17,500	21,000	22,000	21,500

[1] A serious outbreak of Cercosporella foot rot occurred in the spring of 1934, following the open winter of 1933–34. The loss in bushels is estimated as follows: Idaho, 155,000; Washington, 90,000; and Oregon, 30,000. Counties in Idaho in which the disease had not been previously known are Clearwater, Idaho, Latah, Lewis, and Nez Perce.

[2] Trace.

As already stated, the fungus causes a distinct reduction in the number of culms. In culms attacked early in the spring there is a sharp decrease in grain weight per head, as shown in table 2. The data for 1929 were taken from healthy and diseased culms of Hybrid 63 and Hybrid 143 grown in tangled fallen spots at Tygh Ridge, Oreg. The diseased heads were evidently smaller and in many instances contained shriveled grains. Later, however, there was no difference in percentage of germination in the grain from healthy heads and that from diseased heads. The 1930 data were taken from a field of Goldcoin wheat near Alicel, Oreg. The healthy check sample was from a small plot treated by being covered with straw and burned over immediately before seeding.

TABLE 2.—*Effect of cercosporella foot rot on weight of heads and grain in healthy and diseased wheat grown in fields of infested soil on Tygh Ridge, Wasco County, Oreg., and near Alicel, Union County, Oreg., respectively, 1929–30*

Year grown and variety	Average weight per head						Percentage of grain		Average kernels per head			Weight per 1,000 kernels		
	Total			Grain										
	Healthy	Diseased	Decrease	Healthy	Diseased	Decrease	Healthy	Diseased	Healthy	Diseased	Decrease	Healthy	Diseased	Decrease
	Grams	*Grams*	*Per cent*	*Grams*	*Grams*	*Per cent*			*Number*	*Number*	*Per cent*	*Grams*	*Grams*	*Per cent*
1929														
Hybrid 63	0.9244	0.6866	26.0	0.6675	0.4507	32.5	72.2	65.6	24.8	18.1	27.0	24.3	21.8	10.3
Hybrid 143	1.4879	.8923	40.0	1.0884	.5941	45.4	73.2	66.6	39.0	25.3	35.2	27.9	22.9	17.9
1930														
Goldcoin	2.2051	1.1112	49.6	1.5770	.7664	51.7	71.5	69.0	35.2	23.3	33.9	44.0	33.0	25.0

The depressing effect of a very severe attack of cercosporella foot rot on the yield of wheat is shown in table 3 from data obtained in Klickitat County, Wash. The inconsistent data on Hosar are explained by the extreme shattering that occurred in the healthy heads.

TABLE 3.—*Effect of a severe attack of cercosporella foot rot on the yield of several varieties of winter wheat grown in the field on High Prairie, Klickitat County, Wash., 1930–31*

Variety	C.I. no.[1]	Comparative resistance	Acre yield [2]	
			Healthy	Diseased
			Bushels	*Bushels*
Hosar	10067	Very resistant	[3] 29.0	30.6
Queen Wilhelmina		Resistant	46.0	30.9
Hybrid 128	4512	Susceptible	53.3	23.3
Turkey		Very susceptible	47.0	10.9

[1] C.I. refers to accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.
[2] The comparative yields are based on square-rod areas in adjacent diseased and nondiseased portions of the same field.
[3] Yield reduced somewhat by shattering.

DISTRIBUTION ACCORDING TO SOIL TYPES

The distribution and the economic importance of cercosporella foot rot on the various types of soil in the Columbia Basin are shown in table 4. The specific names of the soils are given when known, e.g.,

Hunter's very fine sandy loam, otherwise the soils are listed by class, e.g., very fine sandy loam.

In general, the fine sandy loam and loam soils, which are warm and retain moisture fairly well and have a low hygroscopic moisture coefficient, are the ones that harbor the foot-rot fungus.

The principal exception to this is near Coeur d'Alene, Idaho, on cut-over land in Helmer silt loam. In this area the water table, which lies a few feet under the surface, counteracts the drying conditions that usually occur in heavy soil after the spring rains cease. The area involved on this soil is small, however, in comparison with the total area infested in the nearby prairie lands.

TABLE 4.—*Distribution and degree of severity of the cercosporella foot-rot disease on various types of soil in the Columbia Basin, and the estimated area infested*

Location	Degree of severity	Soil type	Estimated area infested with *Cercosporella*
			Acres
Grande Ronde Valley, Oreg.	Very severe	Alicel fine sandy loam	5,000
Do.	Severe	Alicel sandy loam	500
Elgin, Oreg.	Extremely severe	Very fine sandy loam	2,000
Tygh Ridge, Wasco County, Oreg.	Very severe	Fine sandy loam	2,000
High Prairie, Klickitat County, Wash.	Severe	do	1,500
Seven Mile Hill and vicinity, Wasco County, Oreg.	Moderate	Loam and gravelly loam	1,800
Friend, Oreg.	Trace	White sandy loam	100
Spokane Valley, Wash., and Idaho	Extremely severe	Garrison gravelly loam	6,000
Peone Prairie, Spokane County, Wash.	Very severe	Hunter's very fine sandy loam.	3,000
Peone and Pleasant Prairies, Spokane County, Wash.	Severe	Palouse fine sandy loam	400
Coeur d'Alene, Idaho	Very severe	Helmer silt loam	[1]
Columbia and Walla Walla Counties, Wash.	Moderate to slight	Very fine sandy loam	1,000
Umatilla County, Oreg.	Trace	Loam	[1]
Anatone, Wash.	Moderate	Sandy loam or loam [2]	2,500

[1] Scattered fields.
[2] Approximately Palouse series.

HOST RANGE AND VARIETAL SUSCEPTIBILITY

From 1925 to 1932 several hundred varieties and selections of cereals were studied on infested ground in an effort to find resistant varieties. Most of the material tested has been eliminated on account of susceptibility. Further study is being made of the more promising varieties. The technic of determining comparative resistance has gone through a gradual elaboration, until the following procedure is now used:

Plots are located on summer-fallowed land known to have been infested 2 years previously.

Varieties are sown early in September, usually in duplicate 3-row blocks. (Until 1932 at least 2 and usually 4 or 5 tests were located in widely scattered sections.)

Every fourth plot is sown to a check of Hybrid 128. This variety is commercially grown throughout the areas where cercosporella foot rot is found. It is of average susceptibility.

The injury from foot rot is estimated at harvest time by classifying the culms in several linear feet of the central row in each plot of each variety according to the degree of severity of injury, as shown in table 5.

TABLE 5.—*Degree of severity and percentage of culm injury caused by cercosporella foot rot on various selections of cereals studied from 1925 to 1932*

Degree of severity	Percentage of injury	Description
None	0	No foot rot.
Slight	5	Young eye-spot lesions not penetrating more than a few cells deep.
Moderate	10	Lesions penetrating one fourth to one half way through culm, usually a young developing lesion.
Severe	30	Slightly less than one half way through culm (in extended lesions) to nearly or entirely through culm, but tissue not extensively collapsed.
Very severe	60	Rotted clear through the culm, tissue collapsed; plant evidently will not recover.
Dead [1]		Culms dead and charred by disease, tillers small. When a large number of tillers are dead and diseased the percentage above 40 should be added to the total percentage of injury to approximate the actual percentage of reduction in yield.

[1] Previous to 1932, dead culms were not considered in the estimate except in cases where over 67 percent were dead. The percentage above this figure was added to the total percentage of injury.

The percentage of injury is determined by multiplying the percentage of diseased culms by the average rating on the severity of injury of the diseased culms. The calculated percentage of injury so estimated when checked with yield data has been found to be reasonably accurate.

The relative susceptibility of varieties is determined by direct comparison with the nearest Hybrid 128 check (considered as 100), taking into account observable abrupt changes in soil infestation, influence of adjacent varieties of guard rows, etc.

A summary of the reaction to cercosporella foot rot of certain key varieties and selections is given in table 6. Most of the varieties and selections of the several cereals tested are not listed.

TABLE 6.—*Reaction of certain varieties of cereals and grasses to cercosporella foot rot*

Genus, species, and variety	C.I. no.	Severity rating [1]	Genus, species, and variety	C.I. no.	Severity rating [1]
Avena sativa (oats):			*Triticum vulgare* (common wheat):		
Winter Turf (Gray Winter)	1570	0–10	Queen Wilhelmina (Holland)	11389	60–90
Hordeum vulgare (barley):			Huston	5208	60–70
White Club		[2] 30–50	Hohenheimer (glabrous chaff)	11458	60–70
Tennessee Winter		80–90	Hohenheimer (pubescent chaff)	11459	70–80
Alaska		90–100	Federation	4734	70–80
Secale cereale (rye):			Ridit	6703	90–100
Rosen		0–10	Wheat-rye	8890	90–100
Union Beardless		30–50	Purplestraw	1915	90–100
Aegilops cylindrica		10–30	Dawson	3342	90–100
Aegilops ovata		30–50	Pacific Bluestem	4067	90–100
Aegilops triuncialis		60–70	Triplet	5408	100–110
Triticum monococcum (einkorn)	2433	0–10	Rio	10061	100–110
Triticum dicoccum (emmer):			Harvest Queen	5314	100–110
Black Winter	2337	[3] 10–30	Turkey × Minessa	8035	110–120
Triticum spelta (spelt):			Kharkof	8249	110–120
Alstroum	1773	130–140	Turkey	4429	110–130
Triticum compactum (club wheat):			Goldcoin	4156	110–120
Little Club	4066	60–70	Golden	10063	110–120
Red Chaff sel	10072	60–70	Mosida	6688	120–130
Fortyfold × Hybrid 128	8251	90–100	Jones Fife	4468	120–130
Hybrid 128	4512	100	Kanred	5146	120–130
Hybrid 143	4160	100	Oro	8220	120–130
Hybrid 63	4510	100–110	Minhardi × Minturki	8215	120–130
Jenkin	5177	100–110	Hussar	4843	120–130
Fortyfold × Hybrid 128 (Nursery no. 942)		100–110	Cooperatorka	8861	120–130
Fortyfold × Hybrid 128 (Nursery no. 945)		100–110	Stepniatchka	8862	130–140
Albit	8275	100–110			

[1] Compared with Hybrid 128 checks rated as 100.
[2] Sometimes more resistant.
[3] Sometimes less resistant.

The relative susceptibility of varieties varies somewhat from year to year. For instance, if the rainfall in the period from March to June is heavy the moderately susceptible club wheats become considerably more susceptible. As a rule the Turkey types have been the most susceptible of the wheats, although some of the soft-red and white varieties, including Jones Fife and Goldcoin, are nearly as severely injured.

Susceptibility in a variety usually is associated with one or several of the following characters: Deep-seated compact crowns, abundant tillering, small culms in compact crowns, tall straw, and moderately early maturity.

Resistance in a variety usually is associated with one or several of the following characters: Shallow-seated relatively open crowns, sparse tillering, coarse straw and tough leaf sheaths, short straw, spring habit, and very late maturity.

Hohenheimer (glabrous and pubescent) and Queen Wilhelmina (known also as Holland) are good examples of very late-maturing resistant varieties. The resistance shown by fall-sown spring wheats seems to be a matter of aeration. The stands of these varieties usually are thinned by winter injury, the plants tiller poorly, and therefore conditions around the crowns are drier and not so favorable for the development of the disease. For example, Hybrid 143, a club wheat of spring habit, is resistant to foot rot under average semiarid conditions, but becomes very susceptible when grown in heavy stands under humid conditions.

In the fall of 1930 and in the late winter and spring of 1931 periodic sowings of spring and winter wheats and a winter barley were made in infested soil on Seven Mile Hill, Wasco County, Oreg., and the percentage of injury was determined for each variety by the method previously described. The results are given in table 7.

There was no foot rot in the series sown in the spring and but slight injury in the series sown in February. This agrees with field observations, that spring-sown grain escapes the disease.

In general, the study of varietal resistance shows that none of the adapted commercial wheat varieties is very resistant, but the results suggest the hope that resistant varieties may be developed by breeding and selection.

Extensive search has been made for *Cercosporella herpotrichoides* on various wild grasses growing near infested wheat fields, but so far without definite results. In June of the years 1929, 1931, and 1932, lesions resembling those on wheat were found on *Agropyron inerme* (Scribn. and Smith) Rydb. Attempted isolations from such lesions did not yield the fungus, but there is need for further study of this grass, especially on specimens collected earlier in the season.

PATHOLOGICAL HISTOLOGY

Studies on the histology of foot-rot-infected wheat and barley plants were conducted at Corvallis, Oreg., in 1930–31. With the exception of the early writings of Fron (*13*) and a recent note by Foëx and Rosella (*12*), there is no published information on the pathological histology of this disease.

TABLE 7.—*Cercosporella injury in varieties of spring and winter wheat and a winter barley sown in infested soil in the fall, late winter, and spring at Seven Mile Hill, Oreg., 1930–31*

Crop and variety	C.I. no.	Growth habit	Reaction to cercosporella foot rot	Injury when grain was sown—		
				Sept. 5, 1930	Feb. 20, 1931	Apr. 10, 1931
Wheat:				*Percent*	*Percent*	*Percent*
Minhardi×Minturki	8215	Winter	Susceptible	20.4	1.2	0
Goldcoin	4156	do	do	19.6	.9	0
Hybrid 128	4512	do	do	18.0	.7	0
Purplestraw	1915	Spring	do	17.5	.8	0
Federation	4734	do	Resistant	9.5	.9	0
Huston [1]	5208	do	do		.2	0
Average				17.0	.78	0
Barley:						
O.A.C.[2] no. 7	2814	Winter	Resistant	7.9	1.0	0

[1] Winter-killed when sown Sept. 5; data from this variety not included in average.
[2] O.A.C. = Oregon Agricultural College.

METHODS AND MATERIALS

Most of the study was made on field-infected material killed and fixed in chromo-acetic fixative, dehydrated and infiltrated with paraffin after the n-butyl alcohol method, as used by Zirkle (*30*). Because *Cercosporella herpotrichoides* and associated fungi are usually mingled in the tissues of field-infected plants, supplementary studies were conducted with wheat artificially inoculated in the greenhouse with *C. herpotrichoides*. Where possible, fresh material from infected host tissues grown both in field and greenhouse was studied.

The n-butyl alcohol method usually, though not always, aided in softening the highly silicified and brittle foot-rot-invaded culms. As a further aid, the paraffin blocks were soaked in water for long periods.

Erythrosin in clove oil was the most satisfactory stain for routine laboratory studies. For photomicrographic work, three stain combinations were used: Ehrlich's haematoxylin, safranin and fast green, and Haidenhain's iron alum-haematoxylin.

OBSERVATIONS

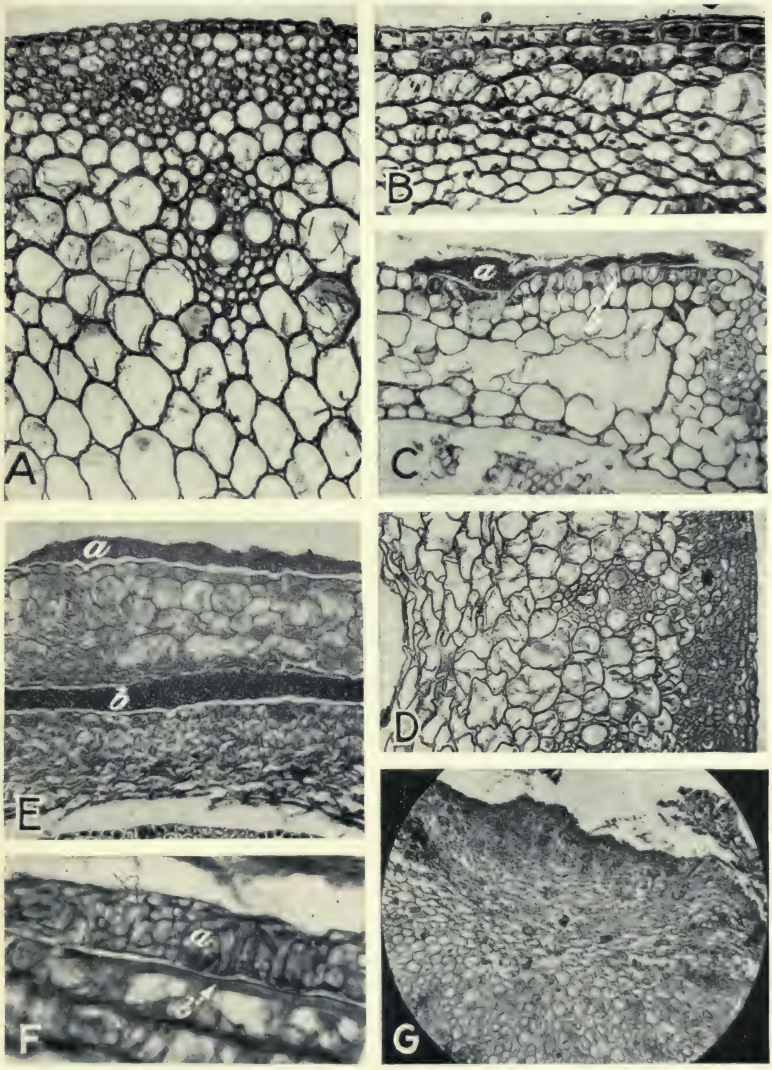
PLANTS INOCULATED IN THE GREENHOUSE

In young plants from seed inoculated at time of sowing the penetration of the outer sheaths, which in these cases frequently are coleoptiles, follows the formation of slight to substantial stromata. Since inoculum is abundant the chances for excess development of stromata are increased. In those cases in the greenhouse where there were secondary infections from spores of *Cercosporella herpotrichoides* the infections took place through stomata and formed eye-spot lesions, and stromata developed later.

PLANTS GROWN IN THE FIELD

EARLY-SEASON DEVELOPMENT

The fungus gains entrance into the outer leaf sheath of the host either directly through the epidermal cells or, more commonly, through stomatal openings and usually precedes its invasion by forming a



CROSS SECTIONS THROUGH LESIONS AT BASE OF WHEAT PLANTS.

A, Section of wheat culm in late June, showing late-season invasion of fungi into culm. The host cells are only slightly injured, the xylem elements being especially resistant. ×120. *B*, Young lesion in culm showing characteristic development of a late-season infection in the Grande Ronde Valley of Oregon. Note thickening of outer cell walls. ×200. *C*, Infection of leaf sheath in the field, High Prairie, Wash., in early April. The fungus formed a stroma *a*, on the outside of the sheath and penetrated through the outer cell layer and again started stroma formation *b*, on reaching the inner side of the cell cavity. ×120. *D*, Culm tissue severely infected in early June with foot-rot fungi. The outer cells are nearly filled with hyphae. The larger vessels were free of mycelia, while the fungus had penetrated to the culm lumen. The stromatic layer on the outside of the culms was torn away in the process of sectioning, together with the remnants of the sheaths. ×85. *E*, Cross section of young tiller in early spring, showing invasion of the two outer leaf sheaths by foot-rot fungi. The sheaths are partly broken down. Note the prominent fungus stromata *a* and *b*. The third sheath has not yet been invaded; the deeper lying sheaths are always resistant to the fungal invasion because they are in a more vigorous condition. ×120. *F*, Stroma *a*, on outside of second leaf sheath, showing cells of macrophyphae, and epidermis showing thickened outer cell walls *b*. ×325. *G*, General view of cross section of shrunken lesion showing collapsed cells. ×25. Note that the larger elements of the xylem remain partly intact.

stroma on the outer surface of the host (fig. 1 and pl. 4). The stromata range in size from a few cells to a mass measuring several millimeters in diameter. The individual cells of the stroma are closely packed, polygon-shaped, heavy-walled, and are olive-brown. The stroma of *Cercosporella* differs markedly from the rhizomorphlike filaments of *Ophiobolus graminis* illustrated by Kirby (*21*).

The stroma on the outer surface continues to grow after the fungus invades the host and usually becomes very extensive through sapro-

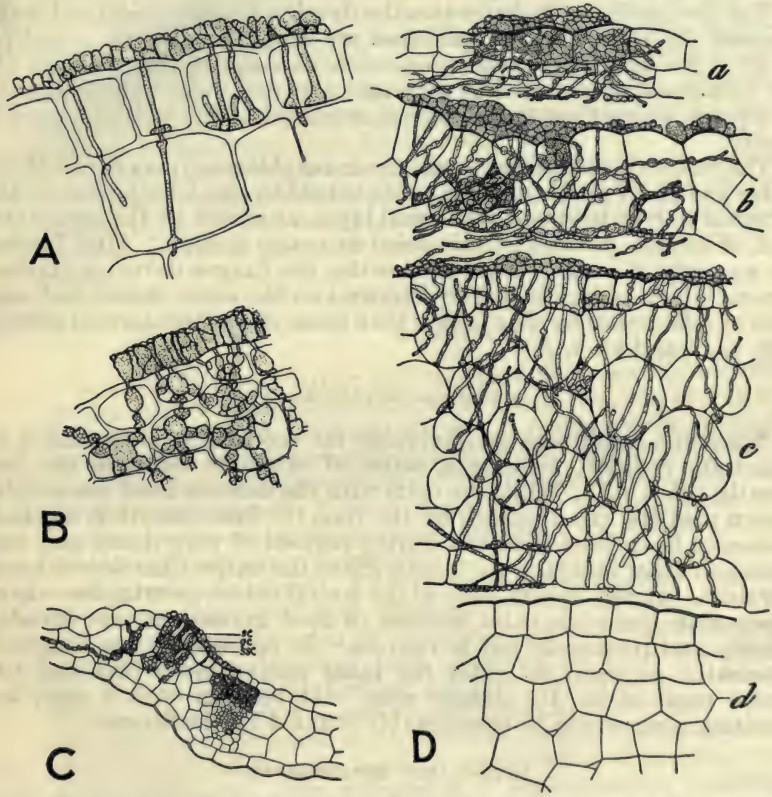


FIGURE 1.—Cross sections through lesions at base of wheat plants: *A*, Young infection in outer leaf sheath, showing direct penetration of the outer cells following the formation of a stroma. Note the slight constriction of the hyphae in passing through the cell walls of the host and the tendency to expand on reaching the inner walls. ×675. *B*, Detail of older infection in leaf sheath, showing increased septation and hyphal development. Shows detail of the passage of the fungus through the thickened cell walls. ×675. *C*, Detail of very young infection in leaf sheath in March, showing penetration through stomatal opening. Note strands passing through stomatal opening (*sc*), fungi in guard cells (*gc*) and stromatic mass completely filling substomatal cavity (*ssc*). ×190. *D*, Portion of a cross section at base of a young wheat tiller 7 weeks after the wheat had been inoculated with *Cercosporella herpotrichoides* at sowing time, in the greenhouse. The fungus has penetrated through the leaf sheaths (*a*, *b*, and *c*) and is about to attack the inner sheath *d*. Note the fungus stromata, the bulbous enlargements on some of the hyphae within the cells, and the thickenings of the cell walls in certain of the infected areas, especially beneath stromata. This section happens to be taken so that no well-developed veins are shown. ×500.

phytic development, producing the charred appearance previously mentioned.

When the fungus penetrates directly through the epidermal cell, the penetrating hyphae are reduced in diameter, but after reaching the cell cavity they increase their diameters again. The writers have not

observed the exaggerated intracellular development shown by Fron (*13*).

Wherever the fungus is retarded by contact with resisting cell walls it produces accumulations of mycelial tissue in the form of bulbous cells and various types of macrohyphae. Frequently these fill the whole cell cavity (fig. 1 and pl. 4). In the stomatal invasions the fungus accumulates a stroma in the substomatal cavity, invades the guard cells, and eventually pushes its way into the adjacent mesophyll cells (fig. 1, *C*).

The host cells in the outer sheaths develop heavily thickened walls beneath the stroma and in cells that are being invaded (fig. 1 and pl. 4, *F*). No lignitubers were seen, such as described by Fellows (*4*) for *Ophiobolus graminis*, but in some cases cell walls were thickened to a point where they approximated one third of the width of the cell cavity.

The fungus is able to penetrate the inner chlorenchyma tissue of the outer leaf sheaf rather readily, but it is held in check for a time by the external wall of the inner epidermal layer, as shown by the accumulation of hyphae present at this point in young lesions. After forcing its way into the space between sheaths, the fungus develops another stroma which is usually larger than that on the outer sheath and consists of cells (macrohyphae) larger than those of the first-formed stroma (fig. 1, *D*, and pl. 4, *E*).

MIDSEASON DEVELOPMENT

When the conditions are favorable for the fungus, it continues to penetrate radially, forming a series of stromata between the leaf sheaths (pl. 4, *E*). While the culm with the delicate head has usually grown past the line of attack by the time the inner sheath is reached, instances have been observed during periods of very damp and cool spring weather in which the fungus killed the entire tiller before heading time. In any season some of the lateral culms, growing less vigorously than the main culm because of food limitations, are invaded rapidly and frequently fail to recover. In figure 1, *D*, the fungus is illustrated as ready to enter the inner sheath before the bud has forced itself above the danger zone. At best, in such a case, the resulting head would be considerably stunted by the fungus.

LATE-SEASON DEVELOPMENT

In its progress through the leaf sheath the fungus tends to grow radially and oblique-radially. After a difficult passage has been made through the epidermal cells of the culm proper, the fungus progresses vertically almost as rapidly as horizontally in the vertically elongated cell tissue immediately beneath the epidermis. There is a tendency for young diseased culms to form a "water-soaked" halo, owing to the fact that the fungus advances faster in the above-mentioned subepidermal elongated cells than in the epidermal cells.

When the parenchyma cells are reached in the interior of the culm the fungus again resumes a steady inward march through the less-resistant cells therein encountered. There is very little hyphal constriction in the invasion of parenchyma tissue.

After the initial horizontal growth into the inner parenchymatous tissue, the fungus progresses vertically for considerable distances.

Various other fungi also invade the lumen area at the same time, the mixed infection sometimes extending several inches up the culm. Such affected culms frequently are lead color, especially when *Cercosporella herpotrichoides* and associated fungi fill the hollow internodes with cottony gray wefts of vegetative hyphae.

In cases of long-extended infection in which the lesions shrivel and the culms fall, the cell contents break down and all but the heavier xylem elements become shrunken and collapse (pl. 4, *G*). The tissue throughout the diseased portion is heavy-walled and brittle. Davidson and Phillips (*3*) recently indicated that excessive lignin development tends to increase the brittleness of culms. The writers have observed that diseased tissue was much more difficult to section than corresponding healthy tissue, and when such diseased tissues were sectioned without special softening measures they broke into small fragments because of their brittleness.

The fact that the xylem elements resist the fungus saves much of the crop from complete destruction. Since the roots are not attacked, the plants, if they reach heading, are seldom killed, because a sufficient number of xylem elements survive to feed the aerial parts of the plants.

THE PATHOGENE

TAXONOMY

In 1931 the senior writer (*29*) accepted *Cercosporella herpotrichoides* as the correct name of the Columbia Basin foot rot, and in the brief literature reviewed on pages 51 to 52, *Cercosporella* is cited by all investigators with the exception of Foëx and Rosella (*8*) who, in 1929, gave *Cercospora herpotrichoides*. Their later reports refer to *Cercosporella herpotrichoides*. While there may be some question of including this species under the genus *Cercosporella*, the writers are accepting this classification for the present.

As previously stated, *Cercosporella herpotrichoides* was originally considered connected with *Leptosphaeria herpotrichoides*. While the two fungi occur together in foot-rot infested wheat in Europe, only negative information has been obtained on their connection. In the United States McKinney reported *Leptosphaeria* on wheat infected with *C. herpotrichoides* near Spokane, Wash. (*23*). *Leptosphaeria* has not been found since, although most of the surveys have been conducted in other areas than the one in which *C. herpotrichoides* was originally found. The cultures of *C. herpotrichoides* studied by the writers were distinctly different from the culture of *L. herpotrichoides* sent by Henry and referred to by Henry and Foster (*19*). Naturally diseased stubble was kept under observation on the ground at Corvallis, Oreg., and in the field at other points, but numerous examinations failed to disclose an ascomycete that might be the ascigerous stage of *C. herpotrichoides*.

All attempts to produce an ascigerous stage of *Cercosporella herpotrichoides* in pure culture have been negative. Numerous strains of the fungus were grown in pure culture at Corvallis, Oreg., during the winter of 1929–30 on various media, and parallel series were stored (1) in the laboratory at approximately 20° C., (2) in the ice box at approximately 12°, and (3) out of doors at fluctuating winter temperatures. The media used were as follows: Potato-dextrose agar (500 isolations); corn-meal agar; corn meal in flasks; wheat heads in test tubes; wheat

straw in test tubes; wheat kernels in flasks; oat and barley kernels in flasks; synthetic media of standard and special formulas; *Melilotus* stems, with water, also with 1-percent glycerine solution; gelatin; unpolished rice; and filter paper in various nutrient solutions and in water.

MORPHOLOGY

The hyphae of *Cercosporella herpotrichoides* are of two sorts: (1) Rapidly growing vegetative hyphae, which are pale chalcedony yellow to olive-brown in color and have narrowly cylindrical cells; and (2) stromatic hyphae with moderately to very thick walls (macrohyphae) and frequently polygonal cells that form charred masses on the outside of culms or sheaths or in the cells of infected culms.

The conidiophores are simple or sometimes branched. In some cases they are swollen at the base and elongated, but usually they are short, erect, subhyaline to hyaline, and rise from macrohyphal subicula. The large ends of the obclavate spores are attached terminally or subterminally and may occur singly or sometimes in pairs. The spores

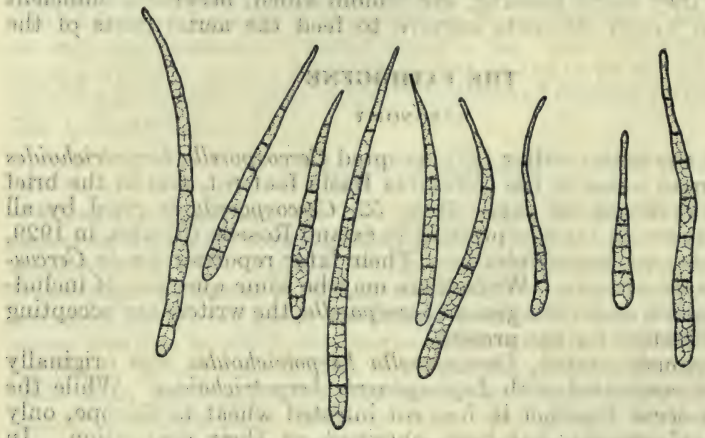


FIGURE 2.—Spores of *Cercosporella herpotrichoides* from culms of foot-rot-infected wheat grown at High Prairie, Klickitat County, Wash., April 1931. ×750.

(fig. 2) are somewhat curved and are 2 to several septate, chiefly 5 to 7 septate. They differ in size, ranging from 1.5μ to 3.5μ by 30μ to 80μ. Most of the spores are 40μ to 60μ long.

PHYSIOLOGY

ISOLATION STUDIES

Numerous pure-culture isolations from diseased tissues have been made on potato-dextrose agar at intervals since 1923. Previous to 1930, the isolations were obtained in June and July, after the disease was well advanced. The data for 1929 are presented in table 8. They show that *Cercosporella herpotrichoides* was by far the most frequently isolated fungus. Isolations from the young lesions yielded *C. herpotrichoides* in a higher percentage of cases than those from the older lesions, but there was not very much difference in the relative number of fungi in different parts of the lesions. The surface stroma was composed almost exclusively of *C. herpotrichoides*.

TABLE 8.—*Kinds and number of fungi isolated from young and old lesions and from various locations in lesions in wheat culms from fields near Imbler, Oreg., and in the vicinity of The Dalles, in Oregon and Washington, during June and July 1929*

Fungus	Cultures obtained from—			Total	Cultures obtained from locations in lesions as indicated					
	Young lesions	Old lesions			At or near margin	Center	Beyond visible margin	General	Surface stroma	Total
		Culms not buckled	Culms buckled							
Cercosporella herpotrichoides	*Number* 95	*Number* 178	*Number* 159	*Number* 432	*Number* 221	*Number* 158	*Number* 48	*Number* 23	*Number* 13	*Number* 463
Wojnowicia graminis	5	15	28	48	22	18	8	6	0	54
Fusaria spp	8	39	30	77	25	37	13	4	2	81
Miscellaneous [1]	5	12	6	23	5	8	2	2	0	17
Total	113	244	223	580	273	221	71	35	15	615

[1] Includes unknown organisms that occurred frequently enough to warrant retention. Bacteria, common molds, and various nonseptate fungi were discarded.

During the season of 1930 isolations were made in March and April, and the results, shown in table 9, indicate that *C. herpotrichoides* was the primary invader.

As the season advances there is a tendency for secondary fungi to obscure the action of *C. herpotrichoides* and this is especially true following heavy rains in June. One of the most common symptoms at this time is the lead-colored stem induced by the various fungi browning the cells of the lumen. Besides the usual *Fusaria* and *Wojnowicia graminis* (fig. 2, *A*), several nonseptate fungi and a Rhizoctonialike fungus accompany *C. herpotrichoides* in these late-season infections.

TABLE 9.—*Kinds and number of fungi isolated from lesions on culms and sheaths of wheat taken from fields in the vicinity of The Dalles, in Oregon and Washington, during March and April 1930*

Date of isolation	Culm or sheath	Culms or sheaths infected by—			
		Cercosporella	*Wojnowicia*	*Fusaria*	Miscellaneous fungi
		Number	*Number*	*Number*	*Number*
Mar. 18 to 21	Culm	17	0	1	1
Mar. 28	do	10	0	0	0
Do	Sheath	7	4	7	18
Mar. 31	Culm	29	0	3	7
Apr. 4 to 7	do	91	9	1	0
Apr. 7	Sheath	24	0	2	3
Apr. 22 and 23	Culm	83	7	3	0
Apr. 25 to 30	do	41	6	3	3
Apr. 29 and 30	do	5	5	4	0

In some cases, *Wojnowicia graminis* alone seemed to extend the lesions caused by *C. herpotrichoides* in the lumen region and produced long discolored internal lesions.

The latter fungus is readily isolated from lesions on overwintering or overwintered stubble in the field.

CULTURAL CHARACTERS

VEGETATIVE GROWTH

The colonies of *Cercosporella herpotrichoides* on potato-dextrose agar [5] are, as previously described (*29*), at first hemispherical mounds of smoke-gray to light grayish-olive velvet-nap mycelium with paler margins. About a week after the fungus is transferred and incubated at 20° C., hyphae begin to grow out from the mounds of mycelia over the surface of the medium. As compared with associated fungi, *C. herpotrichoides* is slow-growing. At a temperature of 21°, colonies of *Wojnowicia graminis* in several dozen petri-dish cultures averaged 74 millimeters in diameter in 11 days, whereas corresponding colonies of *C. herpotrichoides* averaged only 31 millimeters in diameter. The cultures produce small spherical sclerotial aggregates of dark macrohyphae that superficially resemble fruiting bodies.

Wojnowicia graminis differs from *C. herpotrichoides* in forming a looser growth which is olive-brown to olivaceous-black on potato-dextrose agar.

SPORULATION

The appearance of fruiting cultures was briefly mentioned in an earlier article (*29*). The fungus was grown in flasks on sterilized corn meal, and after the usual hemispherical mounds had developed in the laboratory the cultures were placed outdoors in the late fall in temperatures fluctuating between −4° and 16° C. A darker growth immediately started, the mycelium lost its velvety nap, became looser and coarser, and varied in color through several shades of gray to fuscous, with an ultimate tendency to be lighter in color. The coarsening proceeded variably; sometimes loose coremiumlike strands were formed, or more commonly the hyphae gradually clumped together into gray to black microsclerotia or flat sporodochia as the fungus progressed across the surface of the medium. The extreme condition occurred as slimy masses of flesh-pink to carrot-red conidia similar to Sherbakoff's pseudopionnotes (*27*). All of these types were found together or separately. Sometimes fans of growth spread out from the margin of the colony. These were frequently pseudopionnotes, or more commonly they were olive-green to black, flat, stromatic, or chlamydosporelike growths resembling saltants, such as have been observed in *Ascochyta pinodella* (*22*). Spores are produced in tremendous quantities in the pseudopionnotes and on sporodochia. Some cultures produced so little vegetative mycelium that they resembled colonies of bacteria rather than those of fungi. In fact, they were considered as contaminated with bacteria until examination proved the slimy masses were quantities of spores.

Sporulating cultures change the color of the corn meal from a characteristic light maize yellow to a bright lemon chrome. This chromatic development starts at the advancing edge of the colony and gradually extends deep into the medium.

Cultures left outdoors for some weeks and returned to a warm temperature (20° C.) revert to the compact mycelium with velvety nap and tend to lose their chromatic proclivities.

SPORE GERMINATION

The spores studied were obtained from viable sporulating pure cultures. At a temperature of 20° C., germ tubes appear first from the

[5] Difco potato-dextrose agar, pH 5.5, was used.

end cells and later from any cell in the spore (fig. 3). Spores germinate readily, if fresh, either in potato-dextrose agar or in Ranker's medium (*26*), but growth is slow. In one series the germ tubes were only twice the length of the spores at the end of 36 hours, and after 45 hours the mycelia were only 10 times as long as the original spore. After 3 days the colonies were visible to the naked eye, and after 5 days they had developed sufficiently to be recognized as typical *Cercosporella* colonies.

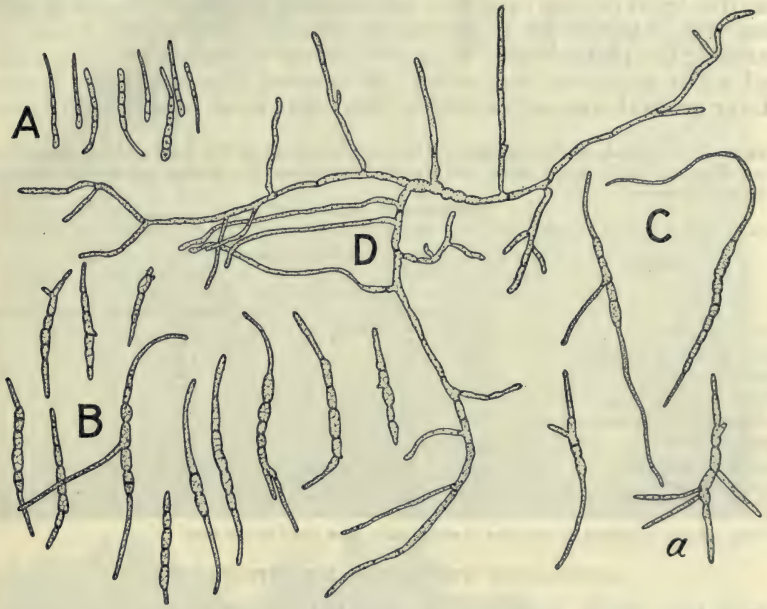


FIGURE 3.—Stages in the germination and early growth of spores of *Cercosporella herpotrichoides* obtained from pure cultures on sterile corn meal and germinated at 20° C. in potato-dextrose agar (pH 5.5). × 420. *A*, Ungerminated spores as taken from corn-meal culture. *B*, Germinating spores 18 hours after transfer to potato-dextrose agar. *C*, Germinating spores 24 hours after transfer to potato-dextrose agar. The spore shown at *a* has several secondary conidia that germinated immediately and lost their identity. *D*, Growth 42 hours after the spore had been transferred to potato-dextrose agar and just before the colonies became visible to the naked eye. Note increase in size of original spore over that of spores shown in *A*. The 6 original cells lie just above the letter *D*. The central cross walls had ruptured by this time.

PATHOGENICITY

ARTIFICIAL INOCULATION STUDIES

As already stated, in order to obtain infection by pure culture inoculation it is necessary to grow the wheat under cool moist conditions. The negative results of previous years may be attributed to the fact that the inoculated plants were kept in greenhouses where the temperatures averaged too high and the humidity was too low.

The result of preliminary inoculation work was briefly reported previously (*29*). Since that time additional and more extensive inoculation studies in the greenhouse and in the field at Corvallis, Oreg., and in fields adjacent to the foot-rot areas have proved that the fungus is a destructive parasite. An example of the severity of attack is shown in table 10. Cereals were sown in Amity silt loam at Corvallis in the fall of 1930, preceding a mild winter. Plants were inoculated in February by laying the oats-barley inoculum at the base of the culms, the soil being too moist to handle at the time. A strip

of grain through the plot was inoculated, and by harvest this grain and a considerable quantity on an adjacent area had nearly all fallen, and almost 100 percent of the culms were diseased. A parallel uninoculated series grown about 200 feet away produced no disease.

The resistance of spring-sown grain has already been discussed in part under host range. Most of the experimental field inoculations on spring-sown grain have been unsuccessful. Spring grain inoculated with pure cultures of *Cercosporella herpotrichoides* in late March was free from disease except in one instance where a 2½-percent infection was obtained at High Prairie, Wash. The winter grain surrounding the plots showed 50 to 100 percent of disease by culm count, and when inoculum was added to some of this naturally infected winter grain it was so severely injured that most of it failed to head.

TABLE 10.—*Result of inoculation on fall-sown cereals in the field at Corvallis, Oreg., on Feb. 4, 1931, with pure cultures of Cercosporella grown on sterile oats and barley kernels*

[Records taken June 25, 1931]

Variety [1]	C.I. no.	Fallen culms	Relative severity of foot rot	Culms			
				Total	Healthy	Diseased	
		Percent		*Number*	*Number*	*Number*	*Percent*
Hybrid 128 wheat	4512	60	Severe	59	3	56	94.9
Hosar wheat	10067	90	do	134	0	134	100.0
Queen Wilhelmina wheat	11389	35	do	122	0	122	100.0
Wheat×rye-wheat	8890	100	do	90	0	90	100.0
Alstroum spelt	1773	93	do	120	0	120	100.0
Wheat×wheat-*Aegilops*		80	do	116	0	116	100.0
Hohenheimer (pubescent) wheat	11459	75	do	85	0	85	100.0
Aegilops triuncialis		50	Moderate	108	0	108	100.0
Einkorn	2433	0	Slight	104	4	107	96.4
Black Winter emmer	2337	45	Moderate	104	0	104	100.0
Hybrid 128 wheat	4512	95	Very severe	110	0	110	100.0
Minhardi×Minturki wheat	8215	100	do	97	0	97	100.0

[1] The varieties are listed in the order in which they were sown in the field.

INOCULATION WITH NATURALLY INFESTED SOIL

Soil from fields known to be infested with *Cercosporella herpotrichoides* was transported to Corvallis, Oreg. Seed of Hybrid 128 wheat was sown in boxes containing this soil and incubated out of doors. Cercosporella foot rot was readily produced.

After preliminary work had shown that the disease would develop under these conditions, wheat was sown in heavy silt loam at Corvallis, and covered with 2 inches of soil from a diseased field in Klickitat County, Wash. As early as November there were indications of injury, and by February, after an open winter, characteristic eye-spot lesions were photographed. Isolations were positive. In June a count disclosed that all varieties in the plot were almost 100 percent diseased and that 70 percent of the culms had fallen and were only two-thirds as tall as those of the checks. All the diseased plants were a peculiar dull green-yellow (pl. 5).

On the basis of these results, studies of varietal resistance were started at Corvallis during 1931–32 and are still in progress. In these studies the grain was sown in 16-foot rows in Newberg sandy loam soil, and each row was inoculated with a shovelful of infested soil from Klickitat County, Wash. Infections resulting in an average injury of 30 percent were obtained the first season.

The disease also develops on wheat grown in naturally infested soil in the greenhouse when temperature and humidity are favorable.

ROD-SQUARE PLOTS OF SEVERAL VARIETIES OF WHEAT AT CORVALLIS, OREG., JUNE 15, 1931.

A, Uninoculated. *B*, Inoculated at seeding time by covering seed with soil from High Prairie, Wash., infested with *Cercosporella herpotrichoides* showing 100 percent of cercosporella foot rot, severe stunting, and many fallen culms.

DISSEMINATION AND OVERWINTERING

Field studies on the role of the spores in the dissemination of *Cercosporella herpotrichoides* have not progressed beyond the preliminary stages.

During the early spring, spores are common on diseased plants in the field, sometimes being produced in great abundance. These spores doubtless have much to do with the sudden increase of infection after heavy rains in the spring. The writers have had difficulty in greenhouse experiments in keeping uninoculated check plants free from infection when placed near inoculated plants. Spores are carried by splashing water. Uninoculated checks kept on benches other than those on which the inoculated plants were kept rarely became infected. There was some evidence that the spores were air-borne in a few cases. Foëx and Rosella (*11*) state that there is evidence that the spores may be air-borne. However, this point needs further study.

During the winter of 1930–31 wheat plants 2 months old were inoculated with spores from a pure culture of *Cercosporella* on corn meal and incubated in a moist cool greenhouse. Typical eye-spot lesions developed in 4 weeks.

Spores kept indoors a few days germinate sparsely and in many cases fail to germinate at all, which suggests that they are not long-lived.

As previously mentioned, the fungus survives the winter on diseased stubble standing or lying in the field. Attempts to isolate the fungus directly from the soil have been unsuccessful.

CONTROL MEASURES

A brief summary of the data on control of cercosporella foot rot is presented in the following paragraphs.

CHEMICALS

Numerous chemicals have been tried for controlling the soil-borne infestation of *Cercosporella herpotrichoides*. While some of these have caused material reduction in the severity of the foot rot, none has given promise of commercial success. The chemicals tried most extensively were organic mercury dusts, alum, aluminum sulphate, mercuric chloride, copper sulphate, flowers of sulphur, bordeaux mixture, and borax.

FERTILIZERS AND AMENDMENTS

There are many references to the use of commercial fertilizers for controlling foot-rot diseases of cereals. Hamblin (*17*) suggested the use of superphosphate at the rate of 156 pounds per acre for control of the Helminthosporium disease in Australia. Martinet (*24*) and Guerrapain and Demolon (*15*) cautioned against the application of excessive quantities of nitrogen, and Gaudineau and Guyot (*14*), in studying the complex of foot rots in northern France, found that lime, iron sulphate, sulphur, superphosphate, and sodium nitrate had no appreciable effect on the disease or diseases. The nitrate fertilizers, however, did not increase the severity of the disease, as had been suggested. Parisot (*25*), who apparently holds that nutrition is the entire cause of soil-borne foot-rot diseases, found that phosphate fertilizers tended to stabilize the growth of the host plant and to reduce foot rot (piétin) in general. According to Parisot,

the heavy application of nitrogen and potassium fertilizers, which tends toward a sudden revival of growth, increased foot rot. Biffen (*1*) reported that a foot rot possibly caused by *Leptosphaeria herpotrichoides* was especially bad on ammonium-sulphate plots. Guyot (*16*) found that nitrate of soda increased foot rot more than the increased yield warranted. She suggested spring application as the safer method. An application in October of approximately 134 pounds per acre (150 kilos per hectare) of potassium nitrate and ammonium phosphate increased foot rot only slightly and increased yield considerably. Foëx (*6*) recommended nitrate of soda and also iron sulphate at the rate of approximately 888 pounds per acre (1,000 kilos per hectare) for controlling foot rot. He mentioned that in this case *Cercosporella herpotrichoides* Fron was found associated both with *L. herpotrichoides* and *Ophiobolus graminis*.

Experiments conducted in the field with standard commercial fertilizers applied in the fall have been repeated many times in all of the major cercosporella foot-rot areas in the Pacific Northwest. The results will not be given in detail. No fertilizers have consistently shown any value in reducing the severity of the foot rot. On the contrary, heavy applications in the fall of fertilizers rich in nitrogen increase the disease. Spring applications of commercial fertilizers have not had any appreciable effect in reducing the foot rot.

Experiments were conducted also in the greenhouse. Various quantities of different commercial fertilizers were added to Newberg sandy loam soil in cubic-foot boxes and 12-inch glazed drainage tiles, the checks being left without fertilizer. Half of the containers were not inoculated, and the other half were inoculated with *Cercosporella herpotrichoides* at seeding time. All were sown to Hybrid 128 wheat. In the soils to which lime or potash was added there was considerable reduction in the percentage of injury from foot rot, and in the soil to which superphosphate was added there was only 5 percent injury in comparison with 68 percent in the untreated checks. This did not agree with the results obtained in the field. The soil used in the greenhouse tests, however, was strongly acid, whereas the soils in the field tests were neutral or only slightly acid. This suggests that on strongly acid soils superphosphate might be of some value in controlling foot rot. In the United States, however, there are no strongly acid soils now known to be infested with *C. herpotrichoides*.

BURNING THE STUBBLE AND HEATING THE SOIL

At La Grande, Oreg., in 1921, 52 percent of cercosporella foot rot was found in a portion of a field from which the stubble had been burned after harvest. An unburned check area showed 54 percent. This indicated little effect from the first season's burning at least.

In September 1929 1 square rod in an infested field near Alicel, Oreg., was covered with a bale of straw and burned over. On the following day Goldcoin wheat was sown on this plot with a hand seeder, and within a few days the same variety was sown on the surrounding commercial field. Early in July 1930 the burned-over plot showed 13.1 percent of foot rot and the surrounding unburned field 69.9 percent.

In order to determine whether the presence of ashes on the surface of the soil was in any way responsible for the decrease in the severity of the disease in the burned portion, an experiment was conducted in

an infested field of Hybrid 63 on Tygh Ridge, Oreg., in the fall of 1930. Straw ashes were mixed into the soil between the wheat plants just after they had emerged. Data taken in July 1931 showed 23.2 percent of injury from foot rot where ashes had been added and 23.5 percent in adjacent untreated portions. It is evident, therefore, that the straw ashes did not reduce foot rot.

On the plot near Alicel in 1929–30 the fire no doubt destroyed the fungus at the surface of the soil, and because of the shallow seeding there probably was no mixing with subsurface-infested soil. The cumulative effect of burning year after year should be studied.

EFFECT OF HARROWING

Field observations have shown that harrowing in the spring increases foot rot slightly if followed by rainy weather; when followed by dry weather, harrowing aids in aerating the topsoil and there is a reduction in the amount of foot rot. It is not desirable to harrow too early in the spring when the soil is most moist and when the likelihood of immediate rains is greater.

TIME OF SEEDING

Evidence not presented here has shown clearly that, other things being equal, the earlier the grain emerges in the fall the greater is the amount of disease that may be expected.

DISTANCE BETWEEN ROWS AND USE OF DEEP-FURROW DRILLS

All experiments show that increased aeration reduces the amount of cercosporella foot rot. During seasons of excessive rainfall, when the growth of wheat is rank, there is no appreciable difference in severity of foot rot in rows 8, 10, 12, or even 14 inches apart. In seasons of reduced rainfall wider spacing decidedly reduces foot rot because of increased aeration. Growers in the Grand Ronde Valley of Oregon are taking advantage of this and are seeding with every other drill row blank. They are getting splendid results in controlling the disease in years when the precipitation is not excessive.

The deep-furrow drill has no value in controlling foot rot. In an experiment conducted on Seven Mile Hill, Oreg., four varieties were sown on four dates in the fall of 1928. In July 1929 the sowings averaged 16 percent of foot rot in the standard drill rows and 17.4 percent in the deep-furrow drill rows. A similar experiment conducted the same year at Imbler, Oreg., gave 76.2 and 78.7 percent of foot rot, respectively, for the two sowings.

RESISTANT VARIETIES

Information on varietal resistance is presented earlier in this bulletin. Hybrid 128, while moderately susceptible, is the most satisfactory wheat to grow on soil infested with *Cercosporella herpotrichoides*. A number of varieties have shown less injury from cercosporella foot rot than has Hybrid 128, but they have not been tested sufficiently to warrant recommendation for commercial growing.

CROP ROTATION

The writers have made general observations on the influence of crop rotation on the severity of cercosporella foot rot, but no actual rotation plots have been available for critical study.

Fortunately, foot rot occurs in areas having slightly more annual precipitation than much of the wheatland in the Pacific Northwest. For that reason, crop rotation can be practiced to some extent on most of the foot-rot-infested land.

SPOKANE RIVER VALLEY AND ADJACENT PRAIRIES

On Peone Prairie the lower ground in fields can be sown to spring grain or legume crops with success (pl. 6). Foot rot, once destructive, is now of comparatively minor importance over much of this locality. In Spokane Valley proper the problem is more acute, and rotation in the rocky soil is not so practicable. Where possible, spring grains, field peas, or sweetclover should be sown.

UNION COUNTY, OREG.

Spring-sown cereals, such as Federation wheat, oats, and barley, may be grown on some of the land in Union County, near Elgin, and to a smaller extent on Sand Ridge, near Imbler and Alicel. Alfalfa, sweetclover, and other legumes (except vetch) should replace winter wheat on certain fields in the Sand Ridge area. Fall-sown White Club (Winter Club) barley will come through a majority of the winters yielding a good crop of grain on foot-rot-infested ground.

COLUMBIA GORGE DISTRICT

Crop rotation is more difficult in the slightly drier Columbia Gorge district. On Seven Mile Hill, Wasco County, Oreg., leguminous crops do fairly well and spring grains can be grown to some extent. These crops are profitable only in seasons when moisture is relatively abundant. However, they cannot entirely supersede winter wheat. On Tygh Ridge, also in Wasco County, in another strictly winter-wheat area, the worst spots of foot-rot-infested soil could well be held over until spring and sown to Federation wheat. On High Prairie winter barley is worth a trial on foot-rot-infested ground. Alfalfa and sweetclover should be used on spots that are chronically infested with the foot rot. The occasional seeding of the usually very badly infested hay strip with some legume is a good practice.

SUMMARY

A foot-rot disease of winter wheat and winter barley caused by the fungus *Cercosporella herpotrichoides* Fron is important in certain portions of the Columbia Basin in Oregon, Washington, and Idaho. The disease is also known to occur in France.

The fungus attacks the base of tillers in early spring, forming elliptical eye-spot lesions on the leaf sheaths. It penetrates into inner tissue, forming lesions in the first or second basal internode of the developing culms. Stromata are formed on the lesions, giving them a charred appearance. The lesions later shrivel, and the culms may buckle and fall under the weight of the maturing head, especially in the case of wheat. *Cercosporella herpotrichoides* usually does not cause severe stunting of the attacked plants nor does it attack the roots of such plants, two characteristics that distinguish it from *Ophiobolus graminis*.

The degree of injury caused each year by *Cercosporella herpotrichoides* varies considerably with seasonal climatic conditions, crop practices, and the application of control measures. The loss by this

METHOD OF CONTROL PRACTICED ON PEONE PRAIRIE, SPOKANE COUNTY, WASH., 1932.

Cercosporella-infested soil in the depression is sown to spring wheat and the uninfested soil on the higher ground is sown to winter wheat.

foot rot is due to reduction in the number of culms, decrease in head size and grain weight, and increased difficulty of harvesting the fallen, irregularly ripening grain. *C. herpotrichoides* is mainly confined to fine or very fine sandy loam prairie soils.

Many varieties of wheat, barley, and rye, and a number of grasses are susceptible to *Cercosporella herpotrichoides*, whereas oats are nearly immune under artificial inoculation conditions. No wild hosts are known. No wheat varieties of commercial importance were found to be resistant to the disease.

The fungus enters either directly through the cell walls of the host or through stomatal openings. It invades intracellularly and forms external and internal stromata on the host. Histological studies of the disease are discussed on pages 9 to 13.

It is shown that the primary invader in the early spring in the plants infected with foot rot is *Cercosporella herpotrichoides*. The conidial stage, which is the only known spore stage, develops on corn-meal cultures incubated under favorable conditions for temperature and humidity. It occurs on infected plants in the field in early spring. The sporulating cultures are fully described. The conidia germinate slowly and after several days produce the smoke-gray colonies characteristic of *C. herpotrichoides*.

Under conditions at Corvallis, Oreg., cereals were severely injured by cercosporella foot rot in naturally infested soil in a cool-temperature greenhouse held at 4° to 20° C. Similar results were obtained in localities in eastern Oregon.

The fungus lives over winter on infected stubble. Spores transmit the disease, although their importance is not known.

Crop rotation, resistant varieties, and time of seeding are important factors in the control of the disease. Fertilizers and chemicals have little value in controlling the disease in the field.

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THE USE OF NAPHTHALENE AGAINST THE JAPANESE BEETLE

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INTRODUCTION

Naphthalene has been investigated extensively by entomologists, both as an insecticide and as a repellent for controlling different insect pests that inhabit soil. During the past 10 years it has been tested against the Japanese beetle (*Popillia japonica* Newm.). Practically all of these experiments with naphthalene were made with the resublimed compound, the crude naphthalene sometimes recommended for soil treatment being too variable in composition to be satisfactory. In view of the widespread interest of entomologists and the public at large in the control of the Japanese beetle, the authors have attempted to bring together experimental data and pertinent facts relating to the use of naphthalene against this insect. The research on this problem has led to a better understanding of the insecticidal value of the compound, and, as a result of these investigations, a quarantine procedure (*54*)[2] for destroying the immature stages of the beetle was adopted in March 1929 and has been in operation ever since.

[1] The writers wish to acknowledge the assistance rendered by R. Wagner, K. B. Rogers, and H. W. Coward, formerly on the staff of the Japanese Beetle Laboratory, in conducting the analytical work for this investigation.

[2] Italic numbers in parentheses refer to Literature Cited, p. 25.

PROPERTIES AND ESTIMATION OF NAPHTHALENE

PHYSICAL PROPERTIES

Naphthalene, $C_{10}H_8$, is a white crystalline compound, occurring in coal tar and obtained by crystallization from the fraction boiling from 356° to 572° F. (180–300° C.). It crystallizes in shining plates that have a characteristic odor and a bitter aromatic taste. Insoluble in cold water and very slightly soluble in hot water, naphthalene is readily soluble in alcohol, benzene, and other organic solvents. It melts at a temperature of 176.2° F. (80.1° C.) and boils at 424.2° F. (217.9° C.). Roark and Nelson (*39*) reported that the specific gravity of a saturated atmosphere at 77° F. (25° C.) and normal pressure, as compared with air, was 1.0004. The vapor pressure is low, ranging from 0.02 mm at 32° F. (0° C.) to 0.21 mm at 95° F. (35° C.). Roark and Nelson (*38*) have calculated that 0.01 pound of naphthalene is required to saturate 1,000 cubic feet of air at 32° F. (0° C.); 0.03 pound at 59° F. (15° C.); 0.035 pound at 68° F. (20° C.); 0.04 pound at 77° F. (25° C.); 0.06 pound at 86° F. (30° C.); and 0.09 pound at 95° F. (35° C.). It is seen that under normal conditions only a small quantity of the compound is required to saturate the atmosphere.

QUANTITATIVE ESTIMATION

BY FORMATION OF NAPTHALENE PICRATE

When undertaking extensive experimentation with an insecticide, it is desirable to have some method for estimating quantitatively the concentration of the compound in order to determine the uniformity of dispersion and the persistence of the material under different conditions. A study was made of the method of Küster (*26, p. 1101*), as modified by Colman and Smith (*8*), to determine the reliability of the procedure for estimating small quantities of naphthalene. This method depends upon the precipitation of naphthalene as naphthalene picrate in the presence of excess picric acid.

Considerable variation was found in the recovery of naphthalene by the picric acid method, although in general the results were consistently low. This variation in the quantity of naphthalene recovered can be attributed to several factors: (1) Some naphthalene sublimed in the upper part of the flask, after the compound was heated with picric acid, although it was shaken occasionally; (2) some naphthalene was absorbed in the rubber stoppers used to seal the flasks; (3) the substitution of cork stoppers eliminated absorption but introduced the factor of leakage; (4) some naphthalene did not react with the picric acid because crystals of naphthalene were occluded by naphthalene picrate; (5) the temperature of the solution during the process of crystallization influenced the yield; (6) the quantity of water used to wash the excess picric acid from the precipitate was a factor because, although naphthalene picrate is not soluble in picric acid, it dissolves appreciably in water. It is obvious that the determination of naphthalene as naphthalene picrate is a relatively slow procedure, and careful standardization of each step in the procedure is necessary to obtain consistent, accurate results.

BY OXIDATION TO PHTHALIC ACID

Calcott, English, and Downing (*5*) have reported that sulphonated naphthalene is oxidized practically quantitatively to sulphophthalic acids by means of vanadic acid in 70 percent sulphuric acid. The

quantity of vanadic acid reacting with naphthalene can be determined from the quantity of standard potassium permanganate required to reoxidize the reduced vanadic acid. In the presence of hot concentrated sulphuric acid naphthalene reduces vanadic acid to the blue divanadyl salt, according to the following equation:

$$18H_3VO_4 + 18H_2SO_4 + C_{10}H_8 = 9V_2O_2(SO_4)_2 + C_6H_4(COOH)_2 + 2CO_2 + 46H_2O$$

The treatment of divanadyl salts with potassium permanganate in hot dilute sulphuric acid changes them into vanadic acid according to the following equation:

$$5V_2O_2(SO_4)_2 + 2KMnO_4 + 22H_2O = 10H_3VO_4 + 2MnSO_4 + 2KHSO_4 + 6H_2SO_4$$

The above equations show that 5 molecules of naphthalene are equivalent to 18 molecules of potassium permanganate; therefore, 1 cc of N/10 potassium permanganate is equivalent to 0.7117 mg of naphthalene.

An experiment was carried on to determine the concentration of sulphuric acid necessary to sulphonate the naphthalene within 1 hour at a temperature of 212° F. (100° C.) Fifty milligrams of naphthalene were added to 10 cc portions of acid of different strengths and heated in closed tubes for 1 hour. At the end of this period, the degree of sulphonation was determined as outlined by Calcott, English, and Downing (*5*). The following results were obtained:

Strength of acid:	*Degree of sulphonation*
5 cc of concentrated sulphuric acid plus 5 cc of water	None
7.5 cc of concentrated sulphuric acid plus 2.5 cc of water	10 percent.
10 cc of concentrated sulphuric acid	100 percent.
10 cc of 15-percent oleum	100 percent.

It was found that sulphonation was incomplete when less than concentrated acid was employed; hot concentrated sulphuric acid, or oleum, appeared to be necessary for the sulphonation of naphthalene. It was concluded that some oleum should be used in the sulphonating mixture to insure that any water present in the sample of naphthalene would not reduce the concentration of the acid to a point where the compound was not completely sulphonated. The sulphonating mixture finally decided upon was composed of 40 parts by volume of concentrated sulphuric acid and 60 parts by volume of 15-percent oleum.

Another experiment was conducted to determine the minimum temperature that could be used in oxidizing the sulphonated naphthalene to the sulphophthalic acids. A standard oxidizing solution was prepared by adding 63 g of pure ammonium metavanadate to 220 cc of distilled water and adding gradually with agitation 780 cc of concentrated sulphuric acid. A standard napthalene solution was prepared by adding 1.13 g of resublimed naphthalene to 40 cc of concentrated sulphuric acid and 60 cc of 15-percent oleum and heating the mixture for 1 hour in a closed flask. The solution was then boiled to remove sulphur dioxide, cooled, and made up to a volume of 1 l with distilled water. Ten-cubic-centimeter aliquot portions of the standard naphthalene solution were then mixed with 10-cc portions

of the standard vanadic acid solution and heated for 1 hour at different temperatures. At the end of the oxidation period each sample was diluted to 500 cc with distilled water and titrated with N/10 potassium permanganate solution. The following equation was used in calculating the results:

Mg naphthalene = total cc N/10 potassium permanganate − cc N/10 potassium permanganate in the reagent blank × 0.7117

The degree of recovery of the 11.3 mg of naphthalene in the samples by oxidizing at the different temperatures is given in table 1. From a consideration of the results it appears that the oxidizing temperature should be at least 266° F. (130° C.). The oxidation of naphthalene at this temperature is practically quantitative, the average error being less than 1 percent.

TABLE 1.—*The effect of the oxidizing temperature on the recovery of naphthalene by the vanadic acid method*

Oxidizing temperature		Naphthalene taken for analysis	Naphthalene recovered			Average recovery
			Maximum	Minimum	Average	
° *F.*	° *C.*	*Mg*	*Mg*	*Mg*	*Mg*	*Percent*
212	100	11.3	9.9	8.1	8.82	78.05
230	110	11.3	10.6	9.6	10.02	88.67
248	120	11.3	10.8	10.0	10.50	92.92
266	130	11.3	11.4	11.2	11.26	99.64
275	135	11.3	11.4	11.0	11.26	99.64
284	140	11.3	11.5	11.4	11.44	101.24
302	150	11.3	11.5	11.4	11.44	101.24

The determination of naphthalene by suphonating and oxidizing to the phthalic acids is a relatively rapid procedure which gives results in close agreement; this procedure is free from the empirical factors and the careful standardization in the different steps of analysis required to obtain consistent results by the methods under which the naphthalene is finally estimated as naphthalene picrate.

INSECTICIDAL ACTION OF NAPTHALENE VAPOR ON IMMATURE STAGES OF THE JAPANESE BEETLE

PHYSIOLOGICAL EFFECT

Naphthalene is generally considered by entomologists to be a weak insecticide; actually, molecule for molecule, it is a more effective fumigant than carbon disulphide, carbon tetrachloride, paradichlorobenzene, and other widely used organic compounds. Tattersfield, Gimingham, and Morris (*47*) found the vapor of naphthalene more toxic than paradichlorobenzene to *Aphis rumicis* L. Lehman (*27, p. 965*) reported that naphthalene was 10 to 14 times more toxic than paradichlorobenzene at the same concentration to the confused flour beetle (*Tribolium confusum* Duv.). In 1924 Fleming (*13*) tested the comparative effectiveness of 43 organic compounds as fumigants against the larvae of the Japanese beetle and found that of these chemicals only benzyl chloride, phenol, and ortho-cresol were more effective insecticides than naphthalene. A molecule of naphthalene vapor was considerably more effective against the larvae than was a molecule of paradichlorobenzene, nitrobenzene, bromobenzene, chlorobenzene, hexachloroethane, carbon disulphide, or carbon tetrachloride.

The effect of naphthalene vapor on the immature stages of the Japanese beetle is not clearly understood. When the creamy-white eggs or larvae of this insect are exposed to the vapor of naphthalene they take on a reddish color which ranges in intensity from light pink to mahogany brown, depending on the period of exposure. In view of the results reported by Shull, Riley, and Richardson (*41*) with the oriental cockroach (*Periplaneta*) *Blatta orientalis* L., this discoloration of *Popillia* eggs and larvae is probably not caused by any change in the chemical composition of the blood. It is possible that the change in the color is due to the reaction of the vapor with the fat bodies in the insect, naphthalene being recognized as a fat solvent. After larvae are exposed to naphthalene vapor for several hours they are unable to walk, but move the head and body convulsively at periodic intervals. As the treatment is prolonged, the larvae gradually become completely paralyzed. The paralyzing effect of vapor of naphthalene has also been observed by Rico (*37*) with the parasitic roundworm *Ascaris lumbricoides* L. This paralysis is followed by death.

RELATIVE RESISTANCE OF EGG, LARVA, AND PUPA OF THE JAPANESE BEETLE

A study was made of the resistance of the different immature stages of the Japanese beetle to the insecticidal action of naphthalene vapor. The insects were placed in suitable cages, without soil, and put into 1-l Florence flasks. Balls of naphthalene were suspended from the stoppers in such a manner that the insects in each flask were subjected to the vapor without coming in contact with the solid chemical. The flasks were maintained at a temperature of 70° F., and at intervals some insects were removed to determine the effect of the vapor. The eggs were placed on the surface of moist peat, kept in the dark, and examined daily until all of them had hatched or decomposed; the larvae and pupae were placed on the surface of moist soil in cross-section trays (*15*, *pp. 6–9*) and observed until the effect of the treatment could be determined. With each test, groups of insects were placed in flasks without naphthalene in order to eliminate the errors introduced by mechanical manipulation. In this experiment 3,800 eggs, 1,300 larvae, and 1,000 pupae were used. The mortality caused by different periods of exposure was determined by the following formula:

$$\text{Percent mortality} = \frac{\text{Number of untreated alive} - \text{Number treated alive}}{\text{Number of untreated alive}} \times 100$$

The results of this experiment are summarized in table 2:

TABLE 2.—*Effect of naphthalene vapor on immature stages of the Japanese beetle at 70° F.*

Period of exposure (hours)	Mortality of—			Period of exposure (hours)	Mortality of—		
	Eggs	Larvae	Pupae		Eggs	Larvae	Pupae
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
12	23.6	6.0	6.0	60	59.4	100.0	.....
24	20.0	82.5	.....	72	100.0	100.0	8.2
36	55.0	98.7	.....	96	100.0	.....	8.2
48	66.5	100.0	10.9	120	100.0	.....	54.0

It was found that the different stages of the Japanese beetle vary in resistance to the vapor of naphthalene. It is apparent that the larva is the stage most susceptible and the pupa the least susceptible to the vapor.

EFFECT OF TEMPERATURE ON INSECTICIDAL ACTION

The rapidity of insecticidal action of fumigants on the immature stages of the Japanese beetle is known to be appreciably affected by the temperature of the atmosphere. An experiment was carried on with 6,000 larvae, at temperatures ranging from 50° to 80° F., to determine the extent to which temperature affected the period required for an atmosphere saturated with naphthalene to kill them. The larvae were removed from soil and exposed at the different temperatures to the vapor in the manner described while determining the resistance of the different immature stages. The results of the different tests are summarized in table 3. It was found that the period of time required for naphthalene vapor to kill the larvae varies inversely to the temperature. The prolonged exposure at the lower temperatures is probably necessary because of the decreased activity of the insect and the smaller quantity of the compound in a unit volume of air. At a temperature of 80° an atmosphere saturated with naphthalene contains 0.77 mg of the compound per liter. This quantity is reduced to 0.55 mg at 70°, 0.42 mg at 60°, and 0.36 mg at 50°. It is apparent that even if the activity of the insect were not reduced at the lower temperatures, a much longer period of time would be required for it to absorb an insecticidal dose of the vapor.

TABLE 3.—*Effect of temperature on insecticidal action of naphthalene vapor on larvae of the Japanese beetle*

Period of exposure (hours)	Mortality of larvae at—				Period of exposure (hours)	Mortality of larvae at—			
	50° F.	60° F.	70° F.	80° F.		50° F.	60° F.	70° F.	80° F.
	Percent	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*
2	-------	-------	-------	2.0	24	0	74.6	82.5	100.0
4	-------	-------	-------	37.5	36	3.5	-------	98.7	-------
6	-------	-------	-------	65.8	48	32.5	-------	100.0	-------
8	-------	-------	-------	94.8	72	42.0	100.0	100.0	-------
12	-------	5.0	6.0	100.0	96	90.3	100.0	100.0	-------
15	-------	-------	-------	100.0	120	100.0	100.0	-------	-------
18	5.0	-------	-------	100.0					

EFFECT OF RELATIVE HUMIDITY ON INSECTICIDAL ACTION

The relative humidity of the atmosphere generally does not affect the insecticidal action of a fumigant as markedly as does the temperature, but it was expected that the relative humidity would modify to some extent the toxicity of naphthalene vapor. An experiment was carried on with 5,400 larvae at a temperature of 70° F. to determine the extent to which the minimum lethal exposure in an atmosphere saturated with naphthalene was modified by the relative humidity. The larvae were placed in Florence flasks which were then conditioned for humidity by passing a stream of air of known humidity through them for a period of 24 hours. A relative humidity of 100 percent was obtained by bubbling the air through distilled water, a relative humidity of 56 percent by bubbling the air through a satu-

rated solution of sodium bromide, a relative humidity of 26 percent by bubbling the air through a saturated solution of calcium chloride, and dry air was obtained by passing the air through concentrated sulphuric acid. After the flasks had been aerated for 24 hours the flow of air was stopped and a ball of naphthalene was suspended in each flask. It is realized that when the movement of the conditioned air through a flask was stopped the relative humidity in the flask was probably modified by the respiration of the insects, but it is believed that this factor was not of great importance. Groups of larvae were removed from the flasks at intervals to determine the effect of the treatment. The results of this experiment are summarized in table 4.

TABLE 4.—*Effect of relative humidity on insecticidal action of naphthalene vapor on larvae at 70° F.*

Period of exposure (hours)	Mortality of larvae at—			
	Zero relative humidity	26-percent relative humidity	56-percent relative humidity	100-percent relative humidity
	Percent	*Percent*	*Percent*	*Percent*
18		24.0	40.0	86.0
24	78.3	83.1	95.9	94.7
48	100.0	100.0	100.0	100.0

The mortality of the larvae exposed to naphthalene vapor was increased with the increase in the relative humidity of the atmosphere. As the period of treatment was prolonged there was less difference between the mortality in the different atmospheres until, with an exposure of 48 hours, all larvae were dead.

TREATMENT OF POTTING SOIL WITH NAPTHALENE CRYSTALS

Nurserymen have a definite need for a method of treating soil to destroy larvae of the Japanese beetle before the soil is used for potting greenhouse plants. The use of soil that has had an insecticidal treatment to destroy this insect is required of nurserymen who ship plants with soil about their roots to points outside the quarantined area. Fleming and Baker (*14*) state that steam sterilization and fumigation with carbon disulphide have been found satisfactory for this purpose.

DOSAGE EFFECTIVE AGAINST LARVAE PRESENT AT TIME OF TREATMENT

It was desired to know whether the application of naphthalene crystals to potting soil could be used as an alternative method. A series of experiments were conducted with sandy loam, clay loam, and a mixture of clay loam and peat moss to determine the possibility of using naphthalene crystals for this purpose. These soils were carefully screened to remove large lumps, stones, and debris, and were then mixed in a moist condition with resublimed naphthalene in quantities ranging from 0.2 pound to 2.1 pounds of the chemical to a cubic yard of soil. The treated soil was then placed in 3-inch pots and set in the greenhouse. On the same day the treatment was applied to the soils, 5 active third-instar larvae were placed in each pot. A total of 3,300 larvae were used in this test. These pots of soil

were maintained for 21 days at approximately optimum moisture for growing plants in a greenhouse where the temperature ranged from 45° to 66° F. Ten days after the larvae were placed in the soils, the pots were examined, and a record was made of the number surviving in each treatment. When the examination was completed and all larvae were removed from the pots, the pots were reinfested and allowed to stand for another 10-day period. At the end of this time another examination was made to determine the number of larvae surviving in each treatment. The mortality resulting from each treatment was then calculated according to the previously mentioned formula. A summary of these data is given in table 5.

TABLE 5.—*Effectiveness of naphthalene crystals in destroying larvae in different types of potting soil, the chemical being thoroughly mixed with the soil*

Crystals applied per cubic yard (pounds)	Mortality of larvae in—					
	Sandy loam		Clay loam		Clay loam and peat	
	When put in soil at time of treatment	When put in soil 10 days after treatment	When put in soil at time of treatment	When put in soil 10 days after treatment	When put in soil at time of treatment	When put in soil 10 days after treatment
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0.2	97.4	0	94.3	0	47.5	13.5
0.4	93.4	0	97.2	0	74.4	39.0
0.6	100.0	0	100.0	0	85.9	7.7
0.8	100.0	4.3	100.0	0	100.0	22.3
1.0	100.0	0	100.0	0	98.7	29.0
1.2	100.0	0	100.0	0	100.0	22.3
1.5	100.0	18.6	100.0	0	87.2	36.6
1.7	100.0	0	100.0	0	100.0	27.7
1.9	100.0	0	100.0	0	100.0	17.7
2.1	100.0	0	100.0	0	100.0	5.6

EFFECT OF ORGANIC MATTER ON LARVICIDAL DOSAGE

It was found that when larvae were introduced into the soil immediately after the application of the chemical the insects were destroyed within 10 days. Naphthalene used at the rate of 0.6 pound per cubic yard was sufficient to kill the larvae in the clay loam and sandy loam; it had to be applied at the rate of 1.7 pounds per cubic yard in order certainly to destroy the larvae in the mixture of clay loam and peat. It is apparent that the organic matter in the soil modifies the effectiveness of naphthalene; the higher the concentration of organic matter in the soil, the less effective the compound is in destroying the larvae. The insecticidal value of the treatment was practically dissipated during the first 10 days. When larvae were introduced into the soils 10 days after the application of the chemical, very few of them were killed, even when the naphthalene was applied at the rate of 2.1 pounds per cubic yard. In view of the results obtained later in the chemical analyses of soils containing naphthalene, no satisfactory explanation can be given for the increased mortality of the larvae introduced into clay loam and peat 10 days after treatment. It will be noted, however, that all results obtained with clay loam and peat are somewhat variable.

DOSAGES REQUIRED TO KILL LARVAE INTRODUCED SUBSEQUENT TO TREATMENT

Another series of experiments was carried on to determine the quantities of naphthalene that would have to be applied to potting soil in order that there would be enough of the compound in the soil to destroy larvae introduced 7, 14, and 21 days after treatment, because it was anticipated that under some conditions the protection of the soil from reinfestation might not be possible. Naphthalene crystals were intimately mixed with moist sandy loam at rates ranging from 0.2 pound to 25 pounds per cubic yard. The soil was then placed in the greenhouse and infested with larvae, a total of 8,400 larvae being used in the experiment. At the end of 7 days the larvae were removed from the soil and the mortality from each dosage was determined. The soil was then reinfested and examined again after a lapse of 7 days. The process was repeated for periods of 14 and 21 days after the initial application of the chemical. The following concentrations of naphthalene per cubic yard of soil were necessary: 0.6 pound to kill larvae introduced at the time of treatment; 17.5 pounds to kill those introduced 7 days after treatment; and 20 pounds to kill those introduced 14 days after treatment. A dosage of 25 pounds per cubic yard destroyed only 32.5 percent of the larvae introduced 21 days after treatment. Apparently the insecticidal value of the treatment is rapidly lost in soil. Relatively large quantities of the chemical must be applied to insure the destruction of any larvae introduced subsequent to treatment. The use of these relatively large quantities appears impractical. Obviously, when only sufficient naphthalene is applied to destroy any larvae present at the time of treatment the soil must be protected from reinfestation.

RELATION OF SOIL LUMPS AND MOISTURE TO REQUIRED DOSAGE

The treatment of potting soil cannot always be carried out under relatively ideal conditions where the chemical is intimately mixed, where the soil is moist but not wet, and where there are no lumps large enough to harbor the insect. An experiment was conducted to determine the effectiveness of the treatment under less ideal conditions. Moist and wet sandy loam were obtained in the field and, without sifting, mixed with from 2 to 10 pounds of naphthalene per cubic yard. The moist sandy loam was of optimum moisture, containing 12 percent of water, and the wet sandy loam was practically saturated, containing 23 percent of water. It was not possible to determine that the natural lumps in the soil contained larvae without breaking the lumps and destroying their value for experiment; therefore, artificially infested lumps of moist and wet sandy loam were prepared in the following manner: A 3-inch pot was partially filled with soil, five larvae were placed on the soil, and sufficient soil was added to fill the pot. The pot was then inverted on washed muslin and carefully removed so that the form in which the soil was molded was not destroyed. The muslin was then wrapped tightly about the soil and tied, forming a lump of soil approximately 3 inches in diameter. Twenty-five hundred of these artificially infested masses of soil, containing 12,500 larvae, were prepared and buried in the different treated soils. During the following week, the temperature of the soils fluctuated between 45° and 60°, averaging 51° F. At the end of 7 days, the larvae were removed and the mortality was determined according to the previously mentioned formula. A summary of these results is given in table 6.

TABLE 6.—*Effectiveness of naphthalene crystals in destroying larvae in soil lumps embedded in moist and in wet* [1] *sandy loam treated with different quantities of the chemical*

Crystals applied per cubic yard (pounds)	Mortality of larvae after 7 days in—		Crystals applied per cubic yard (pounds)	Mortality of larvae after 7 days in—	
	Moist soil	Wet soil		Moist soil	Wet soil
	Percent	*Percent*		*Percent*	*Percent*
2	99.28	97.84	7	100.00	89.85
4	99.98	99.19	8	100.00	90.80
5	100.00	78.09	9	100.00	77.40
6	100.00	68.95	10	100.00	85.20

[1] The authors consider a soil as wet when it contains sufficient water to be puddled readily on manipulation; as moist, when about half saturated with water and in a friable condition.

It was found that in this treatment, when the crystals were not in contact with the larvae, naphthalene had to be applied at the rate of 5 pounds per cubic yard to destroy all of the larvae in moist soil. It should be noted, however, that a dosage of 2 pounds applied directly to moist soil killed 99.28 percent of them. In wet soil the treatment was not effective, even when the chemical was applied at the rate of 10 pounds per cubic yard.

From the data obtained, it was concluded that naphthalene crystals can be relied upon to destroy all larvae in soils to be used subsequently for potting plants, provided the following conditions are satisfied: (1) That the soil is moist, but not wet; (2) that it is free from large lumps; (3) that the temperature is maintained above 50° F.; (4) that the chemical is mixed with the soil at the rate of 5 pounds per cubic yard; (5) that the soil is left undisturbed for 1 week; and (6) that the soil is stored under conditions that will prevent subsequent reinfestation.

DECOMPOSITION OF NAPHTHALENE IN SOIL

That under favorable conditions naphthalene disappears rapidly when mixed with soil is well known. This fact has been recorded by Tattersfield (*46*) and Speyer and Owen (*45*). The disappearance of the compound from soil is usually too rapid to be attributed entirely to volatilization. In fact, Tattersfield (*46*), Thornton (*53*), and Gray and Thornton (*19*) have shown that the loss of naphthalene from soil is due largely to bacterial action. It was of considerable interest to know the rate of disappearance of the compound in soil, particularly when the soils were to be used subsequently for the growing of plants. A series of experiments were therefore carried out in the laboratory to determine by chemical analysis the rate of disappearance of naphthalene from the soil.

Before undertaking a study of the decomposition of naphthalene in soil, several experiments were conducted with known quantities of the compound mixed with soil to determine the best method for removing the chemical for analysis and also to learn how much naphthalene could be recovered. Vaporizing the naphthalene in the soil and carrying it to an absorbing material appeared to be the best procedure for removing the compound from the soil. Naphthalene was mixed intimately with moist sandy loam at the rate of 50 mg to 100 g of soil. The sample was placed in a 500-cc Erlenmeyer flask

and heated on a water bath to 212° F. A stream of air, passed through the soil for 18 hours, carried the naphthalene vapor to the absorber, where it was absorbed in concentrated sulphuric acid at a temperature of 320°.

Several different types of absorbers were tried with varying degrees of success. The most satisfactory was a glass tower 5 feet long, the vapors being introduced at the bottom, where they met a stream of hot sulphuric acid that was trickling slowly downward over glass beads with which the tower was filled. A ground-glass connection fused to the bottom of the tower was fitted into a 60-cc round-bottomed Pyrex flask, which caught the acid coming from the tower. The inlet for the air carrying the naphthalene vapor was just above this fused connection. Resistance wire was wrapped closely around the outside of the glass tower to heat the acid, so that when it finally passed into the glass reservoir it was at a temperature of approximately 320° F. A 60-cc dropping funnel was placed above the absorbing tower and so adjusted that a drop of acid was discharged every 15 seconds. As the air carrying the naphthalene vapor passed up the absorbing tower, the naphthalene reacted with the sulphuric acid and was carried into the reservoir, where it was maintained at a temperature between 266° and 320°. After the soil had been aerated for 18 hours, the flow of air and acid was stopped. The acid in the absorbing tower was allowed to drain for 30 minutes into the reservoir. The reservoir was then removed and the absorbing tower washed with distilled water until the washings discharged from the bottom of the tower were neutral to litmus. These washings were then combined with the acid in the reservoir and made up to a definite volume. Aliquot samples were then taken and oxidized with the standard vanadic acid and the quantity of naphthalene was determined by the procedure previously described.

The results of these preliminary tests showed that practically all of the naphthalene could be recovered from soil by this procedure. When 50 mg of the compound were mixed with soil, the results of analysis showed from 48 to 52.2 mg, indicating at this concentration an error of ± 2 percent. The average quantity recovered was 49.6 mg, or 99.2 percent. An attempt was made to reduce the period of aeration below 18 hours by raising the temperature of the soil from 212° to 266° F. It was found that at these temperatures a black, tarry substance was distilled from the soil and deposited in flakes on the inside of the absorbing tower. This material was insoluble in hot concentrated sulphuric acid, but any of the material carried down mechanically in the washing operation dissolved in the vanadic acid, thus introducing a possible error in the analysis. In order to avoid this difficulty the soil was not heated above 212°.

EFFECT OF ORGANIC MATTER

In order to study the rate of decomposition of naphthalene in the soil two soil mixtures were obtained from a commercial nursery. One was a clay loam mixed with well-rotted cow manure; the other, a mixture of this soil with an equal volume of peat moss. The clay loam had a moisture content of 19.8 percent, an apparent specific gravity of 1.132, and weighed about 1,900 pounds per cubic yard; the mixture of clay loam and peat had a moisture content of 40.3 percent, an apparent specific gravity of 0.878, and weighed about 1,480 pounds per cubic yard. These soils were passed through a 10-mesh sieve.

One portion of each soil remained untreated; the other portions were intimately mixed with naphthalene crystals at the rate of 5 pounds per cubic yard. The naphthalene was added at the rate of 2.6 g to each 1,000 g of the clay loam and at the rate of 3.37 g to each 1,000 g of the clay loam-peat mixture. The treated and untreated soils were placed in 1-gallon stone jars and covered with lids. The loss of moisture in each of the jars was determined daily and sufficient distilled water was added to replace the loss from evaporation. At intervals the soil was removed from one of the jars, thoroughly mixed, and three 100-g samples were taken for analysis. At the same time three samples were taken from one of the jars with soil containing no naphthalene, to serve as a blank in the titration. The samples were analyzed according to the previously described procedure and the results expressed in pounds of naphthalene per cubic yard. The data are summarized in table 7.

TABLE 7.—*Rate of loss of naphthalene from moist clay loam and from a mixture of clay loam and peat at room temperature*

Period after treatment (days)	Concentration of naphthalene per cubic yard in—					
	Clay loam			Clay loam and peat		
	Maximum	Minimum	Average	Maximum	Minimum	Average
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
0			5.00	5.04	4.20	4.68
1	4.49	4.38	4.43	4.21	3.28	3.66
2	4.45	3.96	4.22	3.84	3.49	3.67
3	3.84	3.39	3.81	1.48	.95	1.19
4	3.65	2.59	3.59	.34	.19	.26
5	2.07	1.06	1.49	.17	.00	.07
6	.83	.78	.82	.03	.00	.01
7	.23	.00	.09	.02	.02	.02
8	.02	.00	.01	.00	.00	.00
9	.09	.00	.03	.00	.00	.00

The quantity of organic matter does influence appreciably the decomposition of naphthalene in the soil. In the clay-loam soil the concentration was less than 0.1 pound on the average on the seventh day; with the mixture of clay loam and peat this condition was obtained on the fifth day. Apparently the more organic material there is in a soil the more rapidly the naphthalene disappears.

EFFECT OF REPEATED APPLICATIONS

After soil has been treated with naphthalene at the rate of 5 pounds per cubic yard and stored in such a manner as to prevent reinfestation, there generally would be no necessity for re-treating it; but occasionally the fumigated soil becomes reinfested and then re-treatment is necessary. In such instances the nurseryman should know the rate of decomposition of naphthalene in the soil in order to determine when the soil can be used for potting plants. A mixture of clay loam and peat was treated with naphthalene at the rate of 5 pounds per cubic yard, placed in stone jars, and analyzed at daily intervals until the compound had disappeared. The soil was left undisturbed for 5 days, re-treated with naphthalene at the same rate, and analyzed again at daily intervals. Five days after the second application had disappeared, the procedure was repeated. The results of these tests are given in table 8.

TABLE 8.—*The effect of re-treatment on the persistence of naphthalene in soil*

Period after treatment (days)	Concentration of naphthalene per cubic yard after—								
	First treatment			Second treatment			Third treatment		
	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
0	5.04	4.20	4.68			5.00			5.00
1	4.21	3.28	3.66	4.23	3.90	4.11	4.24	3.92	4.10
2	3.84	3.49	3.67	2.33	1.70	1.97	3.36	3.03	3.19
3	1.48	.95	1.19	.85	.40	.69	2.84	2.47	2.65
4	.34	.19	.26	.08	.00	.03	2.42	1.91	2.16
5	.17	.00	.07						
6	.03	.00	.01						
7	.02	.02	.02				1.21	.94	1.09
8							.92	.69	.79
9							.69	.53	.61
10							.80	.35	.59
11							.48	.19	.38
15							.05	.00	.03
16							.03	.00	.01

Practically all traces of the initial treatment disappeared in 6 days; the second application disappeared in 4 days; but the third application remained in the soil for 16 days. Filamentous fungi developed rapidly during the second treatment but were not noticeably present following the first or third applications. It is probable that the first application stimulated the development of this organism so that it was sufficiently numerous to decompose the second application more rapidly; but the extensive development of fungi following the second treatment probably exhausted the essential food elements in the soil and reduced the fungi population so that the naphthalene was decomposed more slowly. The rapid development of fungi in treated soil gives ground for the suspicion that fungi, like bacteria, have a role in the decomposition of naphthalene in the soil.

The decomposition of naphthalene in the soil is influenced by many factors, the most important of which are the organic matter, the moisture content, the temperature, and the degree of aeration. Under conditions in commercial nurseries the soil should be free from all traces of the compound within 2 weeks after the application of crystals.

EFFECT OF TREATMENT ON SUBSEQUENT GROWTH OF PLANTS

A preliminary experiment was carried on with radishes as indicators to determine the effect of treating soil with naphthalene crystals on the subsequent growth of plants. Sandy loam was treated with naphthalene at rates ranging from 5 to 15 pounds of the crystals per cubic yard of soil. Soil was also treated with mixtures of naphthalene and lime and with mixtures of naphthalene and sulphur to determine the possible effect on the growth of the plants of incorporating these chemicals with naphthalene. The mixtures of naphthalene with lime or sulphur were made up in the ratios of 3 to 1, 1 to 1, and 1 to 3, but because of the similarity of the results obtained when the same quantity of naphthalene was mixed with different quantities of the other chemicals, all of the results with the naphthalene-lime mixtures and with the naphthalene-sulphur mixtures

are grouped together. Immediately after the soil had been treated it was placed in pots in the greenhouse and 100 radish seeds were sown in each pot. The same number of seeds was also sown in untreated soil. Two weeks after sowing, the seedlings in each pot were counted and the effect of the treatment was determined by comparing the number of plants growing in the treated soil with those in the untreated soil. The number in each treatment was expressed as the percentage of the number in the untreated soil. After the observation was completed the plants were removed from the pots and the soil was left fallow for 2 weeks. Each pot was again sown with 100 radish seeds and the process repeated. The results of this experiment are summarized in table 9.

TABLE 9.—*Effect of naphthalene and of mixtures of naphthalene with lime and sulphur on the subsequent growth of radishes*

Concentration of naphthalene per cubic yard (pounds)	Number of plants developing					
	When planted immediately after treatment with—			When planted 30 days after treatment with—		
	Naphthalene alone	Naphthalene and lime	Naphthalene and sulphur	Naphthalene alone	Naphthalene and lime	Naphthalene and sulphur
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
5	63.2	83.1	50.4	78.2	95.6	97.1
6	73.4	71.0	50.0	92.7	97.5	90.5
7	59.1	69.4	47.9	95.6	98.5	95.6
8	62.2	63.2	33.6	98.5	86.9	100.0
9	40.8	57.1	34.7	91.5	95.6	89.8
10	39.8	53.0	44.9	92.7	65.2	76.8
11	34.7	41.8	35.7	75.3	75.3	81.0
12	35.7			71.0		
13	31.6			68.1		
14	25.5			79.7		
15	23.4			79.7		

It was found that when radish seeds were planted in soil immediately after naphthalene crystals had been applied the germination and growth of the plants were seriously retarded. The number of plants was reduced progressively from 63.2 percent in the soil treated at the rate of 5 pounds per cubic yard to 23.4 percent in the soil treated with 15 pounds per cubic yard. The addition of lime or sulphur did not materially change the germination or growth of the plants in the naphthalene-treated soil. When the soil was seeded again 30 days after the naphthalene had been applied there was practically no difference in the development of the plants in the soil treated with different quantities of the chemical up to 10 pounds per cubic yard. Some residual retarding action was apparent because in some pots 20 to 25 percent fewer plants developed in the treated soil. In general, however, the detrimental effect of the naphthalene had largely disappeared from the soil within 30 days after treatment.

From the results obtained with radishes it was expected that treatment of potting soil with naphthalene at the rate of 5 pounds per cubic yard would have little effect on the growth of greenhouse plants and nursery stock, provided the soil was aerated after treatment. A mixture of clay loam and manure was treated with naphthalene crystals, left undisturbed for 7 days, and then spread out in a thin layer for 2 days. At the end of this time no odor of naphthalene

could be detected. The soil was then placed in pots and seeded with pot marigold (*Calendula officinalis*) and common snapdragon (*Antirrhinum majus*). No retardation in the germination of the seeds in the treated soil was apparent; the plants grew normally; and those in the treated soil could not be distinguished from those in the untreated soil. The treatment did not affect the quality or the quantity of the blossoms. Commercial nurserymen applied naphthalene crystals to their potting soil at the recommended rate and used it successfully to grow all varieties of potted plants, among which Norfolk-Island-pine (*Araucaria excelsa*), a species of *Cyclamen*, *Dracaena fragrans*, a species of *Aspidistra*, India rubbertree (*Ficus elastica*), English ivy (*Hedera helix*), Forster palm (*Howea forsteriana*), screwpine (*Pandanus* sp.), *Poinsettia pulcherrima*, bowstring hemp (*Sansevieria zeylanica*), and roses (*Rosa* spp.). At the laboratory, *Azalea amoena* and *A. indica*, *Hydrangea opuloides*, a species of *Deutzia*, *Poinsettia pulcherrima*, and a rose (Dorothy Perkins) have been grown successfully in soil previously treated with naphthalene crystals. In addition it was found that a species of *Dahlia*, a species of *Iris*, and a species of *Phlox* grew normally in soil that had been fumigated with naphthalene.

These tests indicate that plants can be grown successfully in commercial nurseries in soil previously treated with naphthalene crystals. It is expected that if the soil is properly aerated after treatment the commercial nurseryman and greenhouseman will have no difficulty in growing the different varieties of plants.

TREATMENT OF POTTED PLANTS WITH NAPHTHALENE CRYSTALS

One of the problems in the control of the Japanese beetle is the development of a method for destroying the larvae in the soil of potted plants. It has been demonstrated many times that the soil of potted plants left in the field becomes infested with this insect during the summer months. It was thought that a practical method for destroying this infestation might be developed with naphthalene.

HYDRANGEAS IN 6-INCH POTS

A series of experiments were carried on with *Hydrangea opuloides*, growing in 6-inch pots. A group of 600 potted plants of this species were infested by placing 25 larvae on the surface and permitting them to burrow into the soil. One week was allowed for the larvae to become established throughout the soil in the pot. Napthhalene crystals were then applied, using dosages of 14.5, 42.5, and 123 g per pot. In half of the pots the chemical was applied at the surface and in the remainder it was placed under the soil mass. Two weeks after treatment all of the soil was removed from the pots, sifted, and examined to determine the number of living larvae. The mortality caused by each treatment, calculated according to the previously stated formula, is given in table 10. It was found that applying even 123 g of naphthalene at the surface or putting the crystals under the soil in the pots did not kill all of the larvae within this period. In the examination some of the larvae were found within one-half inch of the naphthalene crystals, apparently unaffected by the chemical. The application of the crystals at the surface or under the soil mass in the pots did not appear to have any immediate detrimental effect on the hydran-

geas, but it did seriously interfere with the natural drainage of the pots, and probably over an extended period would have proved injurious to the growth of the plants.

TABLE 10.—*Effectiveness of naphthalene crystals in destroying larvae in 6-inch pots of hydrangeas when applied at the surface or under the soil in the pots*

Crystals applied per pot (grams)	Mortality of larvae—	
	When chemical was applied at surface of soil	When chemical was applied under soil mass
	Percent	*Percent*
14.5	93.29	77.20
42.5	75.50	94.15
123.0	65.60	95.15

HYDRANGEAS IN 4-INCH POTS

It was still considered possible that crystals of naphthalene might be applied effectively to hydrangeas growing in 4-inch pots. One thousand of these plants were infested, each with 5 larvae, in the manner described in infesting the larger pots. Naphthalene crystals were then applied, using 5, 10, 15, and 20 g of the chemical per pot. Some of the plants were treated by applying the chemical at the surface of the soil, some were treated by putting the chemical under the soil in the pots, and others were treated by applying the chemical both at the surface and under the soil. After treatment the soil in half the pots was kept relatively dry and in the others it was kept wet for a period of 2 weeks. At the end of this period, the mortality resulting from each treatment was determined in the usual manner. These data are given in table 11. It was found that the infestation was destroyed in the pots kept relatively dry by applying 15 g of the crystals at the surface or 10 g under the soil, or by putting 2.5 g on the surface and an equal quantity under the soil in the pots. When the soil was kept wet, the infestation was destroyed only when the chemical was applied both at the surface and under the soil. The application of naphthalene in this manner prevented the natural drainage of the pots. The soil, which was watered, remained puddled throughout the period of 2 weeks, a condition undesirable for the proper growth of these plants. In view of the results obtained, it did not seem possible to use naphthalene crystals to destroy an infestation of this insect in pots where plants were growing without causing serious damage to the plants.

On the possibility of destroying the infestation in the soil about the roots of hydrangeas in the process of potting the plants, naphthalene crystals were mixed with soil at the rates of 5, 7.5, 10, 12.5, and 15 pounds per cubic yard. Six hundred hydrangeas were dug in the field, most of the soil was shaken from the roots, and 500 were potted in the treated soil and 100 in untreated soil. The naphthalene was applied to the soil just before it was used in the field in order that there might be enough of the chemical to destroy any larvae present in the small masses of soil adhering to the roots. Two days after being potted the plants with naphthalene about their roots began to show signs of injury and continued to grow worse until at the end of 2 months all were dead or dying. The untreated plants

during this period continued to grow vigorously. Two months after treatment a record was made of the condition of the plants, considering a plant "normal" when the top was growing vigorously and the roots practically filling the pot, "stunted" when it had made only a feeble growth, and "dead" when the roots had made no growth and the top was wilted. A summary of these results is given in table 12. The application of naphthalene crystals in this manner was found to be very detrimental to hydrangeas; none of the treated plants grew normally after the crystals had been placed about their roots. Apparently it is not safe to apply treated soil about the roots of hydrangeas until practically all traces of naphthalene have disappeared.

TABLE 11.—*Effectiveness of naphthalene crystals in destroying larvae in 4-inch pots of hydrangeas when applied at the surface and under the soil in the pots*

Crystals applied per pot (grams)	Mortality of larvae—					
	In soil kept dry			In soil kept wet		
	Chemical applied at surface of soil	Chemical applied under soil mass	Chemical applied both at surface and under soil mass	Chemical applied at surface of soil	Chemical applied under soil mass	Chemical applied both at surface and under soil mass
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
5	100.00	99.34	100.00	70.90	80.95	94.75
10	97.44	100.00	100.00	61.60	79.70	100.00
15	100.00	100.00	100.00	83.60	94.65	100.00
20	100.00	100.00	100.00	19.10	92.86	100.00

TABLE 12.—*Effect on subsequent growth of hydrangeas of mixing naphthalene crystals with soil in process of potting*

Crystals applied per cubic yard (pounds)	Condition of plants 2 months after treatment			Crystals applied per cubic yard (pounds)	Condition of plants 2 months after treatment		
	Dead	Stunted	Normal		Dead	Stunted	Normal
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
5.0	43	57	0	12.5	92	8	0
7.5	67	33	0	15.0	93	7	0
10.0	92	8	0	0	0	0	100

The foregoing experiments show that naphthalene crystals cannot be applied to the soil of potted hydrangeas to destroy the larvae of the Japanese beetle without causing serious injury or death to the plants.

FUMIGATION OF THE SOIL OF POTTED AND BALLED PLANTS WITH NAPTHALENE VAPOR

Naphthalene vapor has been used successfully in greenhouses to control the common red spider (*Tetranychus telarius* L.), the sugar-beet thrips (*Heliothrips femoralis* Reut.), the onion thrips (*Thrips tabaci* Lind.), the greenhouse whitefly (*Trialeurodes vaporariorum* Westw.), and different species of aphids on cucumbers, tomatoes, strawberries, carnations, lilies, azaleas, deutzias, hydrangeas, sedums,

arborvitae, and several other kinds of plants, without causing any serious damage to the plants (*9; 22; 23; 24; 33; 34; 36, p. 69–75; 43; 44, p. 49–50*). In view of these results, it was believed that the immature stages of the Japanese beetle might be destroyed in the soil about the roots of potted plants and balled nursery stock by placing the infested stock in a chamber filled with naphthalene vapor.

VAPORIZATION OF CRYSTALS AND DISPERSION OF VAPORS

Before undertaking the insecticidal investigation, a study was made of the vaporization and the dispersion of the vapor in a 1,000-cubic-foot fumigation chamber. The naphthalene was vaporized by two different methods: (1) By placing the crystals in a metal pan directly upon a hot plate, and (2) by placing the crystals in a metal pan which was floating in hot water. In both methods the relative humidity of the air was maintained at practically 100 percent at a temperature of 80° F. by boiling water continuously in the chamber. When the naphthalene crystals were placed directly on the hot plate the compound vaporized so rapidly that the metal pan was empty in 30 minutes. Under these conditions the compound sublimed very quickly, crystals settled on the walls and ceiling of the chamber, and the air was filled with floating crystals. Fifteen hours after the naphthalene had been vaporized and when no crystals were floating in the air, samples of the air were withdrawn from points 2.5, 5, and 7.5 feet above the floor to determine the concentration of vapor in the atmosphere. Ten liters of air were withdrawn from each point at the rate of 1 l in 4 minutes. The air was then analyzed to determine the concentration of naphthalene. It was found that 15 hours after the naphthalene was vaporized on the hot plate, the average concentration of the vapor in the chamber was 0.44 mg per liter. The quantity of naphthalene theoretically required to saturate a liter of air at a temperature of 80° was calculated by the formula:

$$W=\frac{M}{RT}\times\frac{p}{760}\times 1{,}000$$

where W = weight of naphthalene in milligrams per liter, M = 128.06 the molecular weight (128.06) of the compound, R = the gas constant (0.08204 liter atmosphere per molecule per degree), T = temperature in absolute degrees, and p = 0.113, the vapor pressure of naphthalene in millimeters at 80° F. It was calculated that at a temperature of 80° 0.77 mg of naphthalene was required to saturate 1 l of air. When the average concentration was 0.44 mg per liter the air was only 57 percent saturated with the vapor.

The rapid sublimation of the compound, when the naphthalene was vaporized directly on a hot plate, was considered undesirable. The experiment was repeated, vaporizing the naphthalene in a pan which was floating in water maintained at a temperature of 130° to 140° F. At the end of 15 hours a large part of the crystals still remained in the vaporizing pan. The continuous boiling of water in the chamber to maintain a relative humidity of 100 percent resulted in the accumulation of moisture on the walls and ceiling of the chamber. This moisture appeared to have a cooling effect on the naphthalene vapor, causing crystals of the compound to form on the walls and ceiling. An analysis of the air in the chamber 15 hours after

beginning the vaporization showed that the average concentration was 0.46 mg per liter. With an average concentration of 0.46 mg per liter the air was 59 percent saturated with naphthalene. Vaporizing the compound over hot water reduced the rapidity of sublimation but did not prevent the formation of crystals on the sides of the chamber.

Another experiment was carried on, vaporizing the naphthalene in a chamber with the relative humidity of 90 to 95 percent, to determine whether the absence of moisture on the sides and ceiling of the chamber would reduce the sublimation. At the end of 15 hours, when samples of air were taken for analysis, no crystals of naphthalene were on the walls or ceiling of the chamber. The average concentration was 0.81 mg per liter at a distance of 2.5 feet above the floor, 0.83 mg at a distance of 5 feet, and 0.79 mg at a distance of 7.5 feet above the floor. It was apparent that by maintaining the relative humidity just below the saturation point and vaporizing the compound over water at a temperature of 130° to 140° F. practically a saturated atmosphere of naphthalene vapor could be obtained.

MORTALITY OF LARVAE IN SOIL BALLS AT DIFFERENT TEMPERATURES

An experiment was conducted to determine the period of time required for an atmosphere, with a relative humidity of 90 to 95 percent and saturated with naphthalene vapor, to kill larvae in masses of moist sandy loam, approximately 3 inches in diameter, at temperatures ranging from 75° to 90° F. A total of 1,020 masses of soil were prepared and each was infested with five larvae in the manner previously described. The infested soil was then placed in the 1,000-cubic-foot fumigation chamber and exposed to the naphthalene vapor for periods ranging from 18 to 96 hours. At the end of the predetermined period larvae were removed from the soil balls and placed on trays for observation to determine the effect of the treatment. The mortality resulting from each treatment was calculated according to the previously described formula. These data are summarized in table 13.

TABLE 13.—*Effectiveness of an atmosphere with 90 to 95 percent relative humidity, and saturated with naphthalene vapor, in killing larvae in 3-inch balls of soil*

Period of exposure (hours)	Mortality of larvae at—			Period of exposure (hours)	Mortality of larvae at—		
	75° F.	80° F.	90° F.		75° F.	80° F.	90° F.
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
18			36.4	72	97.5	100.0	100.0
24	18.0	40.0	90.0	96	100.0	100.0	100.0
48	89.2	98.7	100.0				

Apparently this treatment might be effective in destroying the larvae in small masses of soil clinging to the roots of deciduous plants and in the soil balls about the roots of small evergreens, provided the vapor was not injurious to the plants.

MORTALITY OF LARVAE IN POTS

The treatment was then applied at a temperature of 80° F., for periods ranging from 48 to 144 hours, to 3-, 4-, and 6-inch pots of moist soil infested with larvae. At the end of the predetermined

exposure larvae were removed to determine the effect of the treatment. These data are given in table 14. It was found that an exposure of even 144 hours was not sufficient to destroy all of the larvae. Apparently very little of the vapor penetrated the walls of the clay pots. The rate of penetration of the vapor from the surface of the soil appeared to be too slow to make the procedure of practical commercial value.

TABLE 14.—*Effectiveness of an atmosphere with 90 to 95 percent relative humidity, and saturated with naphthalene vapor, in killing larvae in pots of soil at a temperature of 80° F.*

Period of exposure (hours)	Mortality of larvae in—			Period of exposure (hours)	Mortality of larvae in—		
	3-inch pots	4-inch pots	6-inch pots		3-inch pots	4-inch pots	6-inch pots
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
48	88.0	92.0	66.6	120	96.7	98.0	81.4
72	91.4	92.0	82.0	144	98.7	98.7	81.4
96	94.0	94.0	92.6				

EFFECT OF TREATMENT ON PLANTS

Although the insecticidal results were not very encouraging, some tests were made with azaleas, hydrangeas, and barberry to determine the resistance of these plants to the action of the vapor. It was planned to expose these plants to a saturated atmosphere of naphthalene for 1 week at a temperature of 80° F. Plants were removed from the fumigation chamber at intervals of 24 hours and placed in the greenhouse. At the end of 24 hours the leaves on the plants began to show injury from the vapor and all plants exposed to the vapor for 48 hours, or longer, were damaged so seriously that they were of no commercial value.

These experiments demonstrated that the vapor of naphthalene in insecticidal concentration was relatively slow in penetrating small balls or pots of soil. A comparatively long exposure was required to assure the destruction of the larvae. The vapor proved so detrimental to the plants, even when they were exposed for shorter periods than were required to kill the insect, as to preclude its use in commercial nurseries.

NAPHTHALENE AS A REPELLENT TO PREVENT FEEDING BY THE ADULT JAPANESE BEETLE

An experiment was conducted in 1925 to determine the value of naphthalene for protecting ripening peaches from injury by the adult Japanese beetle. Thirty-six balls, each 2.5 inches in diameter, were prepared by pouring liquefied naphthalene into spherical molds and permitting it to crystallize. These balls were hung on the branches of small peach trees on which fruit was ripening. A few beetles were in the tree when the chemical was placed there at 10 a.m. and, although the odor was very pronounced, the beetle population had not diminished at the end of 7 hours. The tree was kept under close observation for 6 days, the temperature ranging from 69° to 95° F. At the end of this period the population of beetles in the tree had greatly increased and all of the fruit was damaged. It was apparent that naphthalene used in this manner is of no practical value.

Metzger and Grant (*30*) made a smudge of naphthalene by mixing the crystals with a slowly burning base of wood flour and potassium nitrate. This smudge was found to be only slightly repellent to the Japanese beetle in orchards of ripening peaches; moreover, the wind in the orchard dispersed the smudge so rapidly as to give no satisfactory control.

The blossoms of hybrid tea roses are among the favored foods of the adult beetle and there is at present no satisfactory method for protecting these plants from injury. An attempt was made to protect the blossoms by periodic applications of naphthalene to the ground under the plants. A bed 5 feet wide and 10 feet long, containing 18 roses of the varieties commonly grown throughout the infested area—Mme. Edouard Herriot, Golden Ophelia, Souv. de Georges Pernet, Norman Lambert, John Russell, Red Radiance, Mrs. William C. Egan, Imperial Potentate, Mme. Jules Bouché, Hadley, Angele Pernet, Los Angeles, Sir David Davis, Caroline Testout, Mme. Léon Paine, Mme. Butterfly, Souv. de Claudius Pernet, and General MacArthur—was selected for experimentation. When, on June 15, 25 rose chafers (*Macrodactylus subspinosus* Fab.) were found on the plants, 1 pound of naphthalene crystals was spread on the surface of the ground under the plants. One hour later the odor was very pronounced. All of these beetles left, but on the following day more were present. The treatment was repeated on June 21, June 28, and July 3, therefore definite odor of the compound was always about the roses during this period. The first Japanese beetle was found on the roses on June 28. The number of beetles increased on the plants, notwithstanding the odor, 25 being removed on July 5, 65 on July 6, and 50 on July 7. The application of naphthalene crystals to the surface of the ground under the plants apparently afforded no appreciable protection.

NAPHTHALENE AS A REPELLENT TO PREVENT OVIPOSITION BY THE JAPANESE BEETLE AND AS A CONTROL MEASURE IN THE FIELD

Many references to naphthalene as a repellent and control for soil-infesting insects are found in the literature, but the reports are often so conflicting that it is difficult to determine definitely the value of the chemical for this purpose. Favorable results with naphthalene against wireworms, larvae of Elateridae, have been reported by Theobald (*50*) and Zappe (*54, pp. 163-165*). Gray and Wheldon (*20*) reported that it was of little value in reducing the number of wireworms. Bencomo (*3*) discounted its value for this purpose, and Theobald (*51, p. 213*) in a later paper stated that it had only temporary value as a repellent against these insects. Tattersfield (*46*) and Miles (*31, pp. 17-21*) concluded that naphthalene was of only limited value because the action of the chemical was so dependent upon thorough distribution in the soil, and the effect was temporary because of its relatively rapid decomposition in the soil.

Blakeslee (*4*) and Peterson (*35*) placed naphthalene crystals about the base of peach trees in the usual manner for killing larvae and repelling adults of the peach borer (*Aegeria exitiosa* Say). They found that it had little larvicidal action and did not prevent the adults from ovipositing. Chamberlin (*6*) found crude naphthalene of little value against the black gooseberry borer (*Xylocrius agassizii* Lec.), when applied about the base of the plants.

Feytaud (*12*) and Hutson (*25, p. 122*) found that spreading naphthalene on the surface of the ground was effective in repelling mole crickets. Some protection of newly planted tobacco against attack by tenebrionid beetles has been obtained by spreading naphthalene about the plants (*10, p. 146*). This treatment has also been found effective in protecting grafted slips of grapevines from attack by these insects (*1*).

Smith and Wadsworth (*42*), Gray (*18*), and Thompson (*52*) found that applying naphthalene between rows of onions killed a high percentage of the onion fly (*Hylemyia antiqua* Meig.). Smith and Wadsworth (*42*), Glasgow (*16*), and Thompson (*52*) reported that the application of naphthalene between the rows of carrots greatly lessened the injury by the carrot rust fly (*Psila rosae* Fab.), although the degree of control obtained by this method was not sufficiently uniform to warrant its use on a commercial scale. Naphthalene has been reported by Thompson (*52*) to be effective against the cabbage maggot ((*Phorbia*) *Hylemyia brassicae* Bouché). The celery fly (*Acidia heraclei* L.) has been repelled by the application of the compound to the soil (*2*). Theobald (*48, Rpt. 1925–26, p. 7*) reported that vegetables were protected from damage by ortalid larvae, (*Myodina*) *Seoptera vibrans* L., by hoeing naphthalene into the soil about the plants. Collinge (*7, pp. 17–18*) found that the larvae of the March flies *Bibio marci* L. and *B. johannis* L., which are introduced into soil with manure or leaf mold and attack vegetables and young coniferous plants, can be controlled by treating the ground with naphthalene.

Glendenning (*17*) found that the migrants of the elm-currant aphid (*Eriosoma ulmi* L.) were repelled from black currant bushes by hoeing naphthalene about the plants. Collinge (*7, p. 7*) obtained some control of the woolly apple aphid ((*Schizoneura*) *Eriosoma lanigerum* Hausm.) by applying naphthalene to the soil about infested trees.

Naphthalene has been used with varying results in the control of white grubs in the soil. McKinney and Milam (*28*) found that applications of naphthalene to tobacco beds gave little control of the larvae of the green June beetle (*Cotinis nitida* L.). Escherich (*11*), Novak (*32*) and Romanovsky-Romanko (*40*) reported that the application of naphthalene to the surface of soil prevented the adult cockchafer (*Melolontha melolontha* L.) from ovipositing. Marie (*29*) stated that applying the crystals at the rate of 1 ounce to 10.75 square feet repelled the females of this insect but did not kill the larvae; Guyot (*21*) reported that this treatment was effective against cockchafers, both as a larvicide and as a repellent. Theobald (*48, Rept. 1922–23, p. 12*) stated that leatherjackets, cutworms, and chafer larvae were killed by naphthalene at the rate of 3 hundredweight to the acre, but concluded (*49, p. 43*) that the use of naphthalene could not be depended on to control the cockchafer.

The value of naphthalene as a repellent for soil-infesting insects was reported to vary considerably. The fact that under some conditions the chemical apparently repelled or controlled some insects in the soil led to the conclusion that it might be of value against Japanese-beetle larvae.

NUMBER OF EGGS DEPOSITED IN NAPHTHALENE-TREATED SOIL

A preliminary experiment was set up in the insectary to determine whether the presence of naphthalene in the soil would reduce oviposition by the beetle. Naphthalene crystals were thoroughly mixed with

the soil at rates ranging from 0.54 pound to 10.80 pounds per cubic yard. The treated soil was placed in 12-inch pots and covered with cages; then 1,000 beetles were introduced into each cage and left with an abundant supply of foliage as food. At the end of 1 week, the soil was removed from each pot and the number of eggs deposited in each pot of treated soil was determined. The results of this experiment are presented in table 15. It was found that the reduction in the number of eggs in the treated soils, as compared with the number in the untreated soil, ranged from 30.8 percent, with a dosage of 0.54 pound, to more than 90 percent with the higher dosages. It was impossible from this experiment, however, to determine whether this apparent reduction in the number of eggs was due to the repellent action of the compound or to the insecticidal action on the insects after they had entered the soil.

TABLE 15.—*The effect on the number of eggs deposited by the female Japanese beetle of mixing naphthalene crystals with soil*

Crystals applied per cubic yard (pounds)	Eggs found in treated soil	Eggs found in untreated soil	Reduction in number of eggs in treated soil as compared with number in untreated soil	Crystals applied per cubic yard (pounds)	Eggs found in treated soil	Eggs found in untreated soil	Reduction in number of eggs in treated soil as compared with number in untreated soil
	Number	*Number*	*Percent*		*Number*	*Number*	*Percent*
0.54	1,777	2,567	30.77	5.40	6	112	94.64
1.08	1,437	2,567	44.02	6.48	5	112	95.53
2.16	389	2,567	84.85	7.56	39	112	65.18
3.24	356	2,567	86.13	8.64	10	112	91.07
4.32	268	2,567	89.55	9.72	9	112	91.97
4.32	9	112	91.97	10.80	22	112	80.36

RESULTS FROM TWO METHODS OF APPLICATION

Another preliminary test was made with naphthalene crystals applied to the surface of fallow ground and to turf. Trays 18 inches square and 3 inches deep were filled with fallow soil and with turf. Some were treated by applying naphthalene to the surface at the rate of 1,000 pounds per acre; others remained untreated. A treated and an untreated tray of each were placed in diagonally opposite corners of a large wire cage, 10 feet square and 8 feet high. Approximately 10,000 adult beetles were liberated in the cage and food was added as required. At the end of 1 week the treated and untreated turf and the fallow soil were examined to determine the number of eggs in each. It was found that the application of naphthalene crystals to the surface of the fallow soil or to turf had not caused a decrease in the number of eggs. When applied to the surface in this manner the crystals disappeared, owing to vaporization, before the experiment was completed.

This experiment was repeated, naphthalene being applied at the rates of 1,000 and 2,000 pounds per acre and mixed with the soil. An examination of this soil at the end of 1 week showed that there were no eggs in the treated soils, although a large number of dead beetles were found. A total of 233 eggs were found in the untreated soil in the cage. The naphthalene apparently did not prevent the females from entering the soil to oviposit but killed them before they laid their eggs.

An experiment was next conducted in a flower garden, heavily infested with adult beetles, to determine whether repeated applications of naphthalene to the soil about the plants would prevent the establishment of a larval population in the soil. The flower garden, 50 feet wide and 90 feet long, was planted in rows 2 feet apart with the following varieties: Pot marigold (*Calendula officinalis*), calliopsis (*Coreopsis tinctoria*), Chinese pinks (*Dianthus chinensis*), blue laceflower (*Trachymene caerulea*), African marigold (*Tagetes erecta*), common snapdragon (*Antirrhinum majus*), sweet scabiosa (*Scabiosa atropurpurea*), strawflower (*Helichrysum bracteatum*), common zinnia (*Zinnia elegans*), and the common nasturtium (*Tropaeolum majus*). In addition to these annuals, there were two rows of sweet-william (*Dianthus barbatus*), a row each of the phloxes Mrs. Jenkins and Champs Elysee, some iris, and several clumps of dahlia. When the Japanese beetle appeared in the garden on July 2, naphthalene was applied between the rows of plants at the rate of 1 pound to 100 square feet, and cultivated into the soil to a depth of approximately 2 inches. While the adult beetle was present in the garden the operation was repeated at weekly intervals up to August 20, a total of 8 pounds of naphthalene being applied to each 100 square feet. The odor of naphthalene was very pronounced in this garden during the summer but it did not repel the beetles from the flowers. Beetles could be found on all of the varieties, the feeding being largely confined, however, to the dahlias, marigolds, and zinnias. The application of naphthalene between rows of plants as in this experiment apparently did not affect the growth of these plants.

In November, a larval survey was made by digging two strips, 3 feet wide, 10 inches deep, and 90 feet long, through the garden and across the rows of plants. In this survey 161 *Popillia* larvae and 9 larvae of *Macrodactylus* were found in the rows of plants, and 30 *Popillia* and 1 *Macrodactylus* larvae between the rows of plants where the crystals were applied. In other words, there were 300 larvae of the Japanese beetle in each 1,000 square feet of this garden. It is not uncommon in the vicinity of this garden to have 750 to 1,500 larvae of the Japanese beetle in 1,000 square feet of soil. It should be noted that when this larval survey was made, 3 months after the last application of the crystals, the odor of the chemical was still pronounced and crystals were found in the soil. No doubt the application of naphthalene crystals did reduce the number of larvae in the garden; the results obtained, however, did not warrant recommending the treatment as a control measure.

SUMMARY AND CONCLUSIONS

Naphthalene has been tested extensively by entomologists as a control for different insect pests inhabiting soil, and in the past 10 years has been investigated as an insecticide and as a repellent against the Japanese beetle.

The methods of determining naphthalene quantitatively were investigated. The determination of naphthalene as naphthalene picrate is relatively slow and requires careful standardization of each step in the procedure to obtain consistent results. The determination of the compound by oxidation to phthalic acid is more rapid and gives results in close agreement.

The physiological action of the vapor on the immature stages of the Japanese beetle is not clearly understood. Eggs and larvae exposed to the vapor become reddish in color, the intensity depending on the period of exposure. The vapor paralyzes the immature stages and finally causes their death. The resistance of the different stages increases in this order: (1) Larva, (2) egg, and (3) pupa. The period of exposure necessary for a saturated atmosphere of naphthalene to kill depends upon the temperature, ranging from 12 hours at 80° F. to 120 hours at 50°. The relative humidity of the atmosphere influences to some extent the insecticidal action on larvae, the mortality increasing with the increase in relative humidity.

The larvae can be destroyed in potting soil by applying naphthalene crystals at the rate of 5 pounds per cubic yard, provided the soil is moist (but not wet) and free from large lumps; that the temperature is above 50° F.; and that the soil is left undisturbed for 1 week. Insecticidal tests and chemical analyses show that naphthalene is decomposed rapidly in the soil and under normal conditions would disappear within 14 days. Organic matter in the soil in the form of peat hastens the decomposition. Different potted plants, including *Araucaria excelsa*, *Cyclamen* sp., *Aspidistra* sp., *Poinsettia* sp., *Rosa* sp., *Hydrangea* sp., and *Deutzia* sp., have been grown successfully in soil previously treated with naphthalene crystals. It was found impossible to apply naphthalene crystals to the soil of potted hydrangeas in sufficient quantity to destroy the larvae without causing serious injury to the plants.

When infested pots of soil and infested soil balls were placed in a saturated atmosphere of naphthalene, the vapor penetrated only slowly into the soil. The best results were obtained by vaporizing the crystals over hot water in an atmosphere having a relative humidity of 90 to 95 percent. The plants, however, could not withstand the long exposure necessary to destroy the insect.

Naphthalene vapor did not protect either roses or ripening fruit from attack by the adult beetle.

Mixing naphthalene crystals with soil at the rate of 1,000 pounds per acre was found, under insectary conditions, to prevent oviposition but did not keep the females from burrowing into the soil. The periodic application and mixing of naphthalene into soil about the roots of annual flowers during the flight of the adult beetle reduced the larval population in the soil; however, the results were not sufficient to warrant recommending the procedure as a control measure.

From this investigation it was concluded that naphthalene when applied to soil is an effective insecticide for destroying the immature stages of the Japanese beetle. It cannot be used in insecticidal concentrations to destroy the insect in the soil about the roots of growing plants. Thus, its use is limited to conditions where the soil can be treated before the plants are set. The compound has little value as a repellent against the adult beetle.

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THE RELATION OF FERTILIZERS TO THE CONTROL OF COTTON ROOT ROT IN TEXAS

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UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D.C.

THE RELATION OF FERTILIZERS TO THE CONTROL OF COTTON ROOT ROT IN TEXAS [1]

By H. V. JORDAN, *associate soil technologist;* P. R. DAWSON,[2] *associate biochemist;* J. J. SKINNER,[3] *senior biochemist,* and J. H. HUNTER, *assistant soil technologist, Division of Soil Fertility, Soil Investigations, Bureau of Chemistry and Soils*

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INTRODUCTION

Cotton root rot is the most destructive plant disease in Texas, in many sections of which it has become an important limiting factor in cotton production. It is also serious in certain portions of other Southwestern States, particularly Arizona, New Mexico, and California; and it occurs in Oklahoma, Arkansas, and Mexico. The causal organism is a soil-inhabiting fungus, *Phymatotrichum omnivorum* which attacks the underground portions of the plants.

[1] The investigations reported herein are a part of correlated studies on this general problem in which the Bureau of Chemistry and Soils and the Bureau of Plant Industry of the U.S. Department of Agriculture, the Texas Agricultural Experiment Station and the University of Texas are cooperating. A number of the experiments were made on substations of some of these organizations and acknowledgment is made of the assistance of H. C. McNamara, superintendent, U.S. Cotton Breeding Field Station, Greenville, Geo. T. Ratliffe, superintendent, U.S. Field Station, San Antonio, Henry Dunlavy, superintendent, substation no. 5, Texas Agricultural Experiment Station, Temple; and other members of the staffs of these stations. Acknowledgment is also made of cooperation of the University of Texas in furnishing premises for laboratory and office use and in extending assistance in many other respects. Valuable assistance in securing field data was rendered by E. R. Collins and W.V. Black, assistant soil technologists, and D. R. Ergle, assistant chemist.

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[3] In charge of cotton soil and fertilizer investigations.

While of greatest economic importance in relation to cotton, root rot attacks many other field and truck crops, particularly legumes and root crops; it infects and frequently kills many shade and orchard trees; and it is often a serious menace to ornamental plants and shrubs. Of the field crops only members of the grass family, such as corn, sorghum, and small grains, appear to be free from attack by the disease. It occurs on many species of native vegetation and appears to be indigenous throughout most of the area over which it extends.

The disease has been found in 196 counties in Texas, as reported

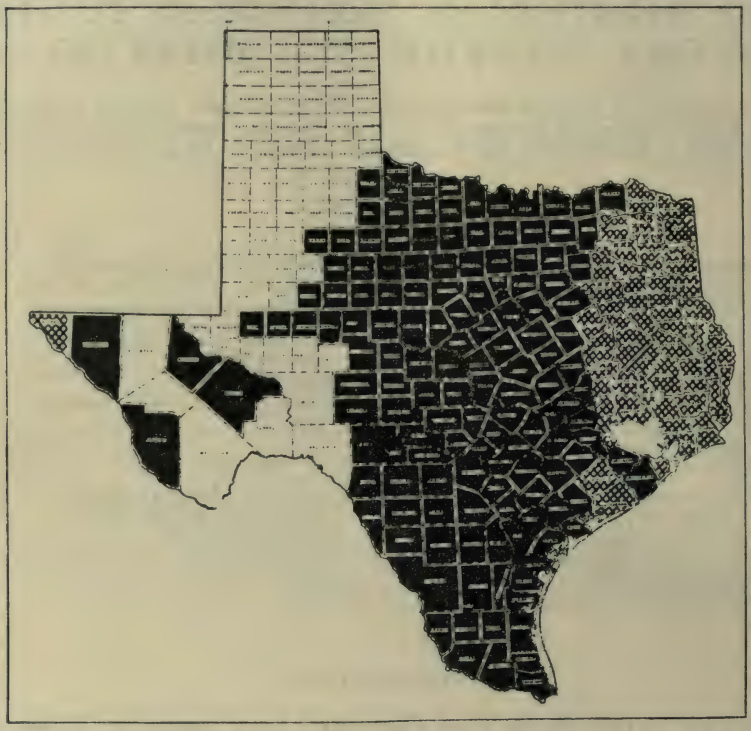

FIGURE 1.—Known distribution of root rot in Texas, black areas indicating counties where it is more prevalent and causes considerable damage, shaded areas counties where the disease is known to be present but is less prevalent, and white areas counties where root rot has not been found, or where no record is available. (Reproduced by permission of the Texas Agricultural Experiment Station, from Bulletin 423 (*66, Fig. 1, p. 6*).)

by Taubenhaus and Ezekiel (*66*).[4] A map showing distribution of root rot in Texas is shown in Figure 1. It is particularly destructive in the black-land prairie section of the State, characterized by heavy clay soils, predominantly calcareous and alkaline in reaction. In light, sandy, acid soils occurring in portions of east Texas, cotton root rot is of minor importance. The annual losses to the Texas cotton crop have been estimated by Taubenhaus and Ezekiel (*66*) at 10 to 15 percent for the State as a whole; but in seasons favorable to root rot the losses in certain localities may greatly exceed these figures. Including the damage to many plants other than cotton affected by the disease, the figure for the average aggregate annual

[4] Italic numbers in parentheses refer to Literature Cited, p. 72.

losses in Texas has been set by the authors cited at approximately $100,000,000.

The damage to cotton is caused by the destruction of plants before maturity of the crop. The fungus infects the roots, destroys the epidermal and cambium layers, and causes the plants to wilt and die

FIGURE 2.—*A*, Root-rot spots in cotton field on Houston clay, Dallas County. *B*, Large field on Houston black clay, Caldwell County, in which cotton has nearly all been killed by root rot. Grass has grown up in places where cotton plants died early in the season. Photographed September 11, 1931.

very quickly. In central Texas the first plants to die usually succumb in June. Killing progresses throughout the crop season at rates varying with the soil moisture, temperature, and other factors not all of which are known. Losses in cotton vary with the proportion of plants which die and their stage of development when death occurs. In Figure 2 are shown root-rot spots in cotton fields and a large field in which nearly all cotton has been killed.

PREVIOUS INVESTIGATIONS

The fungous nature of cotton root rot was first recognized by Pammel in 1888 (*42*, *43*). In 1907 Shear (*56*) described the ozonium or vegetative stage of the organism; while Duggar (*10*) in 1916 reported the conidial stage. In recent years numerous studies (*6*, *8*, *9*, *11*, *12*, *13*, *14*, *15*, *16*, *21*, *24*, *25*, *27*, *29*, *30*, *31*, *32*, *33*, *37*, *38*, *39*, *44*, *45*, *53*, *54*, *57*, *61*, *62*, *63*, *64*, *65*, *66*, *67*, *68*, *69*, *70*) in Texas and Arizona by investigators of the Bureau of Plant Industry and the Texas Agricultural Experiment Station have greatly extended the knowledge of the life history and physiology of the root-rot fungus, the range of cultivated and wild plants affected, the mode of spread and dissemination, means of overwintering and perpetuation, behavior under field crop conditions, and the relation of the fungus to environmental factors.

Investigations by the same agencies on the control of root rot (*1*, *6*, *11*, *12*, *13*, *14*, *20*, *21*, *22*, *23*, *26*, *27*, *28*, *29*, *31*, *32*, *40*, *46*, *47*, *48*, *49*, *54*, *58*, *59*, *63*, *66*, *70*) have covered a variety of lines of attack. Experiments have been conducted with barriers of sorghum, toxic materials, or open trenches; with soil disinfectants and other toxic materials; and with soil-acidifying agents, such as sulphur and marcasite. Tests have been made of the comparative resistance or susceptibility of different strains, varieties, or species of plants. Extensive trials have been carried out with clean fallows, rotation with nonsusceptible crops, modified tillage, and with application of manure and fertilizers. While no practical means of actually eradicating the disease on a field scale have been forthcoming, measures of control have been developed that offer promise for application under limited conditions.

As far as accumulated evidence indicates, the causal organism of cotton root rot is a soil-inhabiting fungus, and effects its damage through parasitism of the underground portions of susceptible host plants. It should, consequently, be amenable to control through modification of the environmental or soil conditions as they affect the organism or its hosts. Previous experiments on control of the disease by modified tillage or use of soil amendments have had this end in view. Similar approaches to the problem of control have been followed in the case of many other plant diseases, where modification of the soil environment has been accomplished by the application of plant food and soil amendments, or through changed tillage methods. Treatments of this type may be effective either through making the soil less favorable for the causal organism or more favorable for the production of a healthy, disease-resistant plant.

To cite a familiar example, control of the common scab of potatoes has been effected through use of chemical treatments or fertilizer materials which tend to increase or maintain a degree of soil acidity recognized as unfavorable to the disease. The date and character of tillage have been reported to influence the severity of foot rot in wheat, in experiments conducted in Kansas (*55*). The use of liberal quantities of commercial fertilizers has led to material control of the root rot of peas, through delaying onset of the disease and actually decreasing its severity (*18*, *19*). The results of investigations in Mississippi (*34*, *35*, *36*) indicate that potassium salts may be beneficial in reducing damage from Fusarium wilt of cotton; and experiments

in Arkansas (*74*) showed definite control of the disease after application of potash-containing fertilizers to soils on which such fertilizer treatment led to stimulation of plant growth and increased yields of seed cotton.

Some previous experiments on the use of fertilizers in relation to control of cotton root rot have been reported. Manure treatments, as described by Scofield (*54*), Taubenhaus and Killough (*70*), and Ratliffe and Atkins (*46*), gave negative or inconclusive results. King and Loomis (*14, 26, 27*), however, have demonstrated a progressive decline in root-rot infestation, following the application of manure and other organic residues over a period of years. Limited trials with commercial fertilizer, reported by Taubenhaus and Killough (*70*) yielded negative or inconclusive results. Later work by the Texas station (*6, Repts. 41, 42, 43; 12; 14; 66*) and by Ezekiel and Neal (*13*) has not shown any direct reduction in root rot, except in pot experiments where the rates of application were excessive. Increases in yield that might offset losses occurred in some instances.

SCOPE OF THE PRESENT INVESTIGATIONS

In 1928, the Division of Soil Fertility undertook a program of investigations in Texas on the relation of soil fertility and the use of fertilizers to the control of cotton root rot. Recognizing that the disease is much more widespread and destructive on certain soil types, or on certain areas of a given type, than on others, studies were directed toward ascertaining what, if any, differences in soil properties are correlated with this unequal distribution. The results have been productive of much fundamental information regarding the characteristics of the prevailing soils; have shed further light upon the soil preferences of the fungus; and have served as a basis upon which to plan and conduct field trials. The data obtained have emphasized the significance of the problem of factors affecting soil fertility.[5]

Other investigations have been concerned with the effects of deep tillage. The most prevalent soils of the black-land prairie section of Texas are characteristically heavy and highly colloidal. Surface drainage is almost everywhere satisfactory, but internal drainage is deficient. Accordingly a modification of soil conditions through deep tillage has been attempted, with striking results in the suppression of root rot.

A further very important phase of the investigations consisted of a series of field fertilizer experiments, inaugurated in 1928 and continued through the succeeding seasons. The object of these experiments was to study the effects of added plant food upon the maturity and yield of the cotton crop growing under conditions of root-rot infestation, and upon the resistance of the plants to the disease. The work has been done exclusively with cotton, and with a few exceptions the experiments have been conducted in fields uniformly infested with root rot.

Detailed reports of the studies on soil characteristics and on the effects of subsoiling are reported elsewhere. This bulletin presents a progress report of the field experiments with fertilizers from 1928 to 1931, inclusive.

[5] Members of the staff of the Austin station of the Bureau who rendered valuable assistance in securing data are Prinston Jenkins, H. A. Nelson, John Parker, H. E. Cone, and L. M. Green.

These field experiments have been confined almost entirely to the black-land prairie section of Texas in which cotton root rot is widely prevalent and of great economic importance. The fields have been so located, however, as to cover the range of variations in climatic conditions and soil types characteristic of this section.

CLIMATE

The section in which the investigations were conducted is characterized by a climate distinctly subhumid in the extreme southern part, with rainfall gradually increasing to the north. The mean annual rainfall at San Antonio is 27.18 inches; at Austin, 34.08 inches; at Temple, 33.96 inches; at Waco, 35.26 inches; at Dallas, 36.16 inches; and at Greenville, 37.63 inches.[6] Normally, a period of hot, dry weather occurs during the latter half of June, July, August, and September, and at this time evaporation and transpiration are high. The relatively low rainfall complicates the problem of securing maximum returns from added plant food, and this is made even more acute by its unfavorable distribution.

The season of 1928 was characterized by a wet period in early summer. Rainfall was plentiful in the early part of the growing season of 1929 also. The summer, however, was quite dry in the northern part of the section, although in the southern part rains continued well into July. 1930 was characterized by a comparatively wet spring and a very dry and hot summer, the conditions becoming more extreme in the northern part of the section. 1931 was almost the reverse, with a dry period in the early growing season, followed by fairly well distributed rains and generally less extreme temperatures.

Taubenhaus and Dana (*62*) have shown that rainfall during the growing season is of major importance among the climatic factors influencing the severity of cotton root rot. Rains at this time cause more rapid spread of the disease and consequent increased destructiveness. This correlation is borne out in these experiments. Plant mortality, with its resultant loss from root rot, was high in 1928. In 1929, the disease was much more destructive in the southern part of the section than in the northern. In 1930, losses from root rot were not large on any of the fields occupied by the tests. Losses in 1931 were of considerable magnitude throughout the section.

SOILS

The black-land prairie section of Texas is characterized by its predominant soils of very dark color and heavy clay texture, which when wet assume a waxy, sticky consistency, leading to the common name of "black waxy land." These soils are widely known for their productivity, which has remained at a remarkably high level. Almost no fertilizer and very little manure are used; in many fields cotton is grown practically continuously; and the use of cover or green-manure crops is not common.

The most prevalent soils are those of the Houston series which, according to Carter (*5*), covers about 80 percent of the total upland area of the section. The most important members of this series are Houston black clay and Houston clay. Soils of the Wilson series,

[6] Rainfall figures compiled from U.S. Weather Bureau's Climatological Data, Texas Section (*72*).

including both the clay and the clay loam, are second in extent. The terrace correlatives of the Houston and Wilson soils, classified in the Bell and Irving series, respectively, are important in local areas. Other soil types of minor extent occur in the general section. Experiment fields were located on representative areas of these soil types.[7]

DETAILED PLANS OF THE EXPERIMENTS

These experiments were planned according to the well-known triangle system for fertilizer experimentation (*52*). The triangular diagram was originally suggested by Schreinemakers in 1893 (*50*) and again by Bancroft (*2*) in 1902 for application in physical chemistry where graphic representation of percentage composition of three component parts is involved. Its application to plant-nutrient studies was originated by Schreiner and Skinner (*51*) in a study involving nutrient solutions; and it has since been used extensively in aqueous culture investigations (*60*, *71*). Its first application to field fertilizer experiments was in a rotation experiment at Arlington Experiment Farm, Va., and at Pennsylvania State College (*41*); it has since been used extensively in field experiments with many crops throughout the United States. The scheme has proved valuable as a basis for preparing fertilizer mixtures, charting data, and interpreting results. Its application in the fertilizer industry has been suggested by Bear (*3*).

The fertilizer analyses [8] used in the present work are shown in the diagrams in figure 3. It will be noted that all mixtures contain a total of 15 percent of plant food. Those represented at the apexes of the triangle contain only 1 of the usual components of a fertilizer mixture, namely, nitrogen, phosphoric acid, and potash. Those represented along the boundary lines contain 2, and those in the interior of the triangle 3, of the components of a complete fertilizer.

It will be noted further that the mixture represented at the top apex contains 15 percent of nitrogen; those on the line just beneath contain 12 percent; and those on successively lower cross lines contain 9, 6, and 3 percent, and no nitrogen, respectively. A similar arrangement for phosphoric acid will be noted when reading from the lower left; and for potash when reading from the lower right. Thus any proportion of the fertilizer elements can be plotted in a triangular representation such as this, although those actually used differed from each other in steps of 3 percent.

Such a series of fertilizer analyses is of special value because of the facility with which the results can be interpreted. In a field which shows major response to phosphoric acid, for example, response would be of a low order to ratios containing none of this constituent. The response would be progressively greater to ratios containing respectively, 3, 6, 9, 12, and 15 percent. An actual example of such an instance is furnished by the results of the Craig experiment for 1928, represented diagrammatically in figure 20, *A*. The trend of response here is unmistakable. A similar trend, differing only in the location of maximum response, is shown in the plotted results from other field experiments.

[7] Acknowledgment is made of the assistance of W. T. Carter, senior soil scientist, Division of Soil Survey Bureau of Chemistry and Soils, in correlating the soil types on which the experiments were conducted.

[8] Throughout this bulletin the figures in a fertilizer analysis refer, respectively, to the percentages of nitrogen, available phosphoric acid, and potash.

The complete series of 21 ratios was applied in only two of the experiments reported here, namely, those on the Craig and Oscar Nelson fields. For the other experiments a selection was made of 9 fertilizers, including those at the apexes of the triangle and others at interior key points. These analyses are represented by figure 3, *B*.

The restriction of most of the experiments to 9 ratios was found necessary in order to confine the plots to areas as uniform as possible in respect to soil and root-rot infestation, without too greatly reducing the size of individual plots. The map of a typical experiment field indicating by black lines the distribution of dead cotton when the field was selected is shown in figure 4. Root rot spreads characteristically in all directions from initial centers of infection. Invasion of narrow plots by infection originating in adjacent plots might partially or completely mask any effect of a given plot treatment upon the disease. Accordingly, in most of the experiments, the plots were from 6 to 8 rows in width and from 200 to 250 feet in length. One exception was the Craig experiment, where 21 ratios were employed with but two-row plots. In this case limitation to narrow plots was necessary in order that all should transect an area of relatively uniform root-rot infestation. The plots were, however, approximately 500 feet in length, about half of which was in noninfested ground. In the experiment at the United States Cotton Breeding Field Station at Greenville, two-row plots, 400 feet in length, were replicated three times. The Oscar Nelson experiment, comprising 21 fertilizer ratios, was on noninfested ground and was laid out with four-row plots.

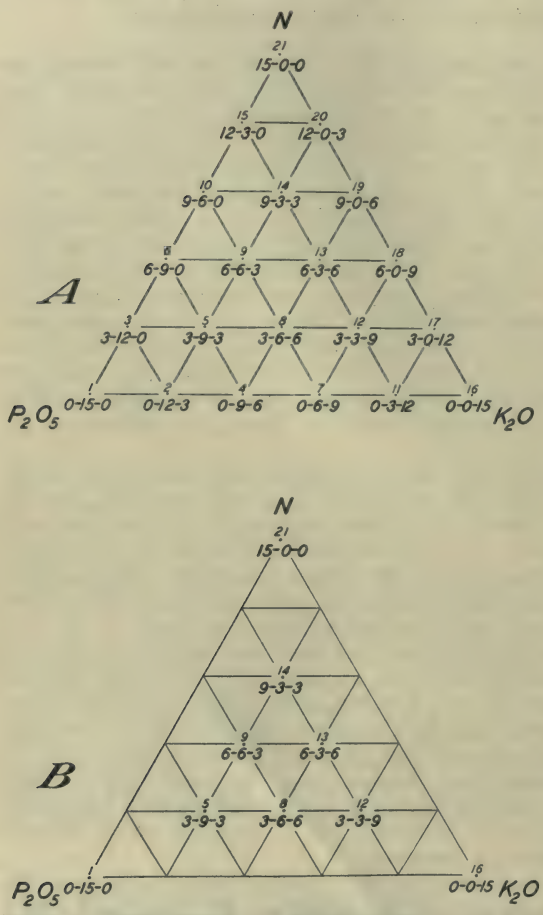

FIGURE 3.—Triangle diagrams of 21 fertilizer analyses (*A*), and of the 9 fertilizer ratios used in most of the experiments (*B*).

The plots were arranged in series in which at least every fourth plot received no fertilizer and served as a check plot. In making

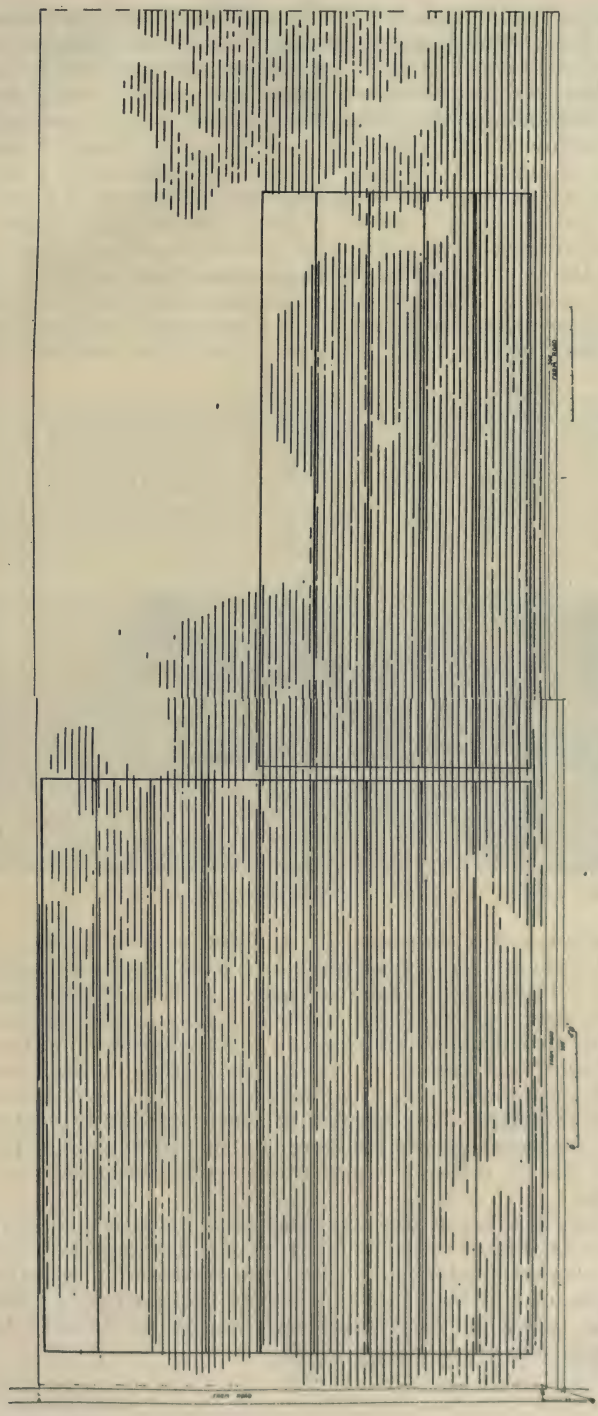

FIGURE 4.—Diagram of a typical experiment field, the black lines showing the distribution of dead cotton at the time the ground was selected and before experimental treatments began; J. W. Jones field, series 1, November 4, 1928.

comparisons of yields, treated plots adjoining check plots were compared with those checks, and the interior one of three adjacent treated plots with the average of the two nearest checks. Such a method of comparison reduces to a minimum the errors arising from soil variations and unequal distribution of root rot. A different arrangement was followed at substation no. 5 of the Texas Agricultural Experiment Station at Temple. Here the plots were grouped in three tiers, the center one of which was untreated. Accordingly, there was a check plot adjacent to each treated plot. Each treatment was replicated eight times in 1929, but owing to a reduction in the area of the experiment in the succeeding years only four replications were retained. Plots in this experiment were 9 rows by 44 feet.

The fertilizer mixtures employed in the triangle ratio experiments were compounded from the commonly used commercial materials.

FIGURE 5.—Method employed in applying fertilizer to experiment plots in most of the experiments.

Except where specific statement to the contrary is made, nitrogen was derived from one third each nitrate of soda, sulphate of ammonia, and cottonseed meal; phosphoric acid was from superphosphate, and potash from sulphate of potash. These experiments were supplemented by comparative tests of various sources of nitrogen and phosphoric acid; and many of the newer, highly concentrated fertilizers were compared with the more commonly used lower grade goods. The fertilizers were applied in most cases at the rate of 600 pounds of 15-percent goods per acre, or the equivalent. In a few experiments lower rates of application were compared with this standard rate.

Applications in most of the experiments to be described were made a week to 10 days in advance of planting, and bedded on. A type of distributor was used which deposited the fertilizer in a rather concentrated stream and about an inch below the bottom of the furrow as shown in figure 5. The placement was thus directly beneath where the seed was eventually planted.

The experiment fields were under close observation throughout the season; and map records of the distribution of cotton killed by root rot were made at frequent intervals.

Most of the experiments were conducted in cooperation with representative farmers and landowners of the section. A number

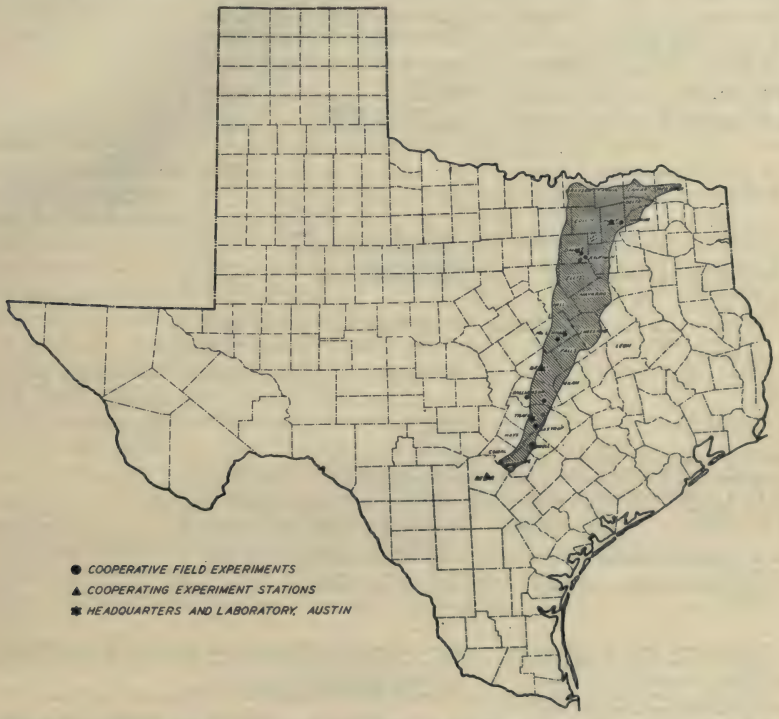

FIGURE 6.—Location of field experiments in Texas, the shaded area representing the major black-land prairie section, according to Carter (*5*).

were carried out with the cooperation of field stations of the Bureau of Plant Industry and of the Texas Agricultural Experiment Station. The geographical distribution of the work is indicated on the map in figure 6. Further information with regard to the fields is given in table 1.

TABLE 1.—*Location of experiment fields, soil types, and duration of experiment*

Name of field [1]	County	Soil type	Duration of experiment	Remarks
R. W. Craig	Hunt	Wilson clay loam	1928–31	
United States Cotton Breeding Field Station.	do	Wilson clay	1928–31	
A. J. King	Dallas	Houston black clay, flat phase.	1929–31	
E. B. Range [2]	do	Houston black clay, non-calcareous phase.	1929–31	
W. E. Jones [3]	do	Houston black clay	1930–31	Results in 1930 not comparable due to irregular planting.
J. W. Jones (White estate, owner).	do	Bell clay	1929–31	First planting of 1930 crop destroyed by hail; replanted crop severely damaged by bollworm.
J. B. Earle	McLennan	Miller silty clay loam, heavy-subsoil phase.	1929–31	
J. J. Cooper	do	Houston clay	1931	
Substation no. 5, Texas Agricultural Experiment Station.	Bell	Houston black clay	1929–31	
Carl Stried [4]	Williamson	Denton clay	1931	
A. Peterson (Nelson estate, owner).	do	do	1929–31	
O. Nelson [3] (C. E. Nelson estate, owner).	do	Irving clay	1929–31	Yields in 1929 not comparable due to insect injury.
W. F. Voelker	Travis	Houston black clay, flat phase.	1929–31	Poor stand on part of field in 1930. Yields not comparable.
W. H. A. Nelson, experiment no. 1.[5]	do	Houston black clay, gravelly phase.	1929–31	
W. H. A. Nelson, experiment no. 2.[6]	do	do	1931	
W. C. Blanks [3]	Caldwell	Houston black clay, flat phase.	1930–31	
Blanks plantation, experiment no. 1.[5]	do	Houston clay, flat phase	1931	
United States San Antonio Field Station.	Bexar	Houston clay loam	1929–31	

[1] Names given the fields are those of owners or operators of the farms on which the experiments were conducted. The authors acknowledge here the valuable assistance rendered by these farm owners and operators in connection with the conduct of experiments on their land.

[2] Primarily a test of acidifying agents and special fertilizer materials. Results considered here only in connection with concentrated fertilizers.

[3] Fields not infested with root rot. The experiments were conducted to test fertilizer effect without the variations introduced by an unequal distribution of root rot.

[4] Rotation and fallow experiment under the supervision of H. C. McNamara, superintendent, U.S. Cotton Breeding Field Station at Greenville. Fertilizer supplements applied in 1931 only.

[5] Primarily deep-tillage experiments, a number of fertilizer supplements included.

RELATION OF FERTILIZERS TO COTTON ROOT ROT

Two well-defined effects of fertilizers in crop production, both of which should have value as means of evading or offsetting cotton root-rot losses, are respectively, accelerated maturity and increased yields. Acceleration of maturity is of particular significance in relation to a progressive disease such as root rot; while increased yields, if of sufficient magnitude, would fully compensate for resultant losses.

It was shown (*6, Rept. 42, p. 116*) for the season of 1929, at the Temple substation of the Texas station, that cotton which died of root rot in July was practically a total loss in so far as the crop was concerned. Plants dying in August produced 41 percent of a crop; in September, 85 percent; and in October a full crop. The proportion of a crop produced under like conditions will probably vary somewhat from these figures in other seasons and at other locations, but such variations will not be great. It follows, therefore, that a

gain of 2 or 3 weeks as a result of accelerating maturity through fertilizers should result in materially larger yields of cotton.

Such an acceleration of maturity must of necessity be reflected in final yields under conditions where a progressive dying of plants occurs throughout the season. It will not be such an important factor in fields free of root rot; or, as is sometimes the case, where cotton does not die until practically mature. It would afford, therefore, insurance against excessive losses from the disease.

Any increase in yield from fertilizer will of course tend to counterbalance the loss from root rot. The extent of loss in any individual field can be estimated only approximately; accordingly, the magnitude of fertilizer effect needed, completely to counterbalance the loss, is necessarily indefinite.

Acceleration of maturity will probably contribute in a very substantial way to increased yields in many cases where root-rot infestation occurs. These two effects of fertilizers are manifestly more or less correlated. Combined they will constitute what might be termed indirect control of the disease.

Other effects of fertilizers in relation to plant disease may lead to more direct control. Accelerated growth and enhanced vigor of plants resulting from adequate supplies of readily available plant food may reduce their susceptibility to attack by root rot or may prolong their period of survival even after infection. Consideration should also be given to a diminished virulence of the disease as a consequence of the influence of fertilizer treatments on the soil environment of the causal organism or upon the activity of competing organisms.

The extent to which such effects have been revealed in the experimental results and their significance in relation to cotton root-rot losses will be developed in the data herein reported.

RESULTS FROM FERTILIZERS ON THE SEVERAL SOIL TYPES

RESULTS ON HOUSTON BLACK CLAY

Houston black clay is one of the most fertile and highly prized soils of the Texas black-land section. It occurs usually in less-eroded situations. The surface soil is a black, highly colloidal clay, which grades into a brown or yellowish-brown clay subsoil. The parent material is marl or chalk. Both soil and subsoil are calcareous, although in this respect the soil differs in degree in different locations.

Experimental data from fertilizer tests on this soil type include 3 years' results on the King field in Dallas County and on the experiment in cooperation with substation no. 5 of the Texas station at Temple, Bell County. Two years' results are included on the Voelker field [9] in Travis County and on the Blanks field in Caldwell County. One year's data are presented on the W. E. Jones field [10] in Dallas County. Summaries of the detailed results are given in tables 2 to 6 and the data are shown graphically in figures 7 to 11.

[9] A poor stand of cotton was obtained on a portion of this field in 1930. The results are accordingly not comparable for the entire experiment; and are not included here.

[10] The results on this field in 1930 were not comparable, owing to irregular planting.

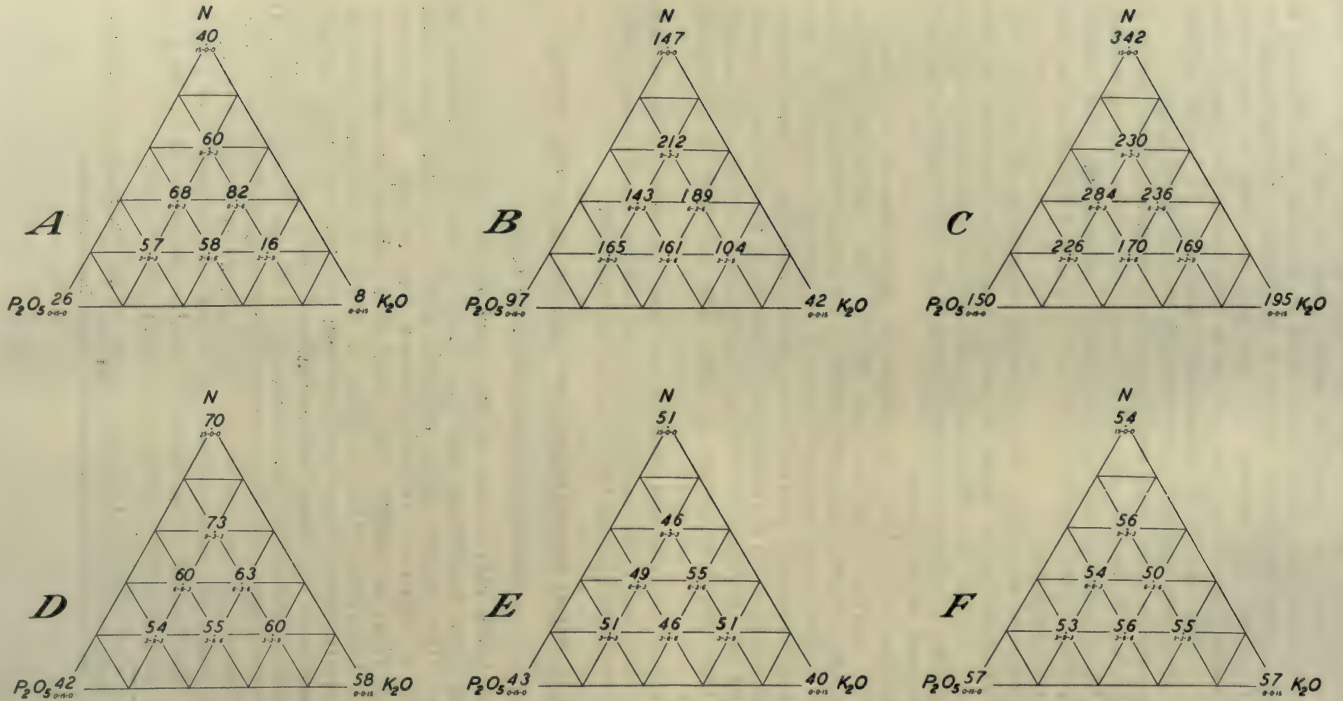

FIGURE 7.—Increases in yield of seed cotton in pounds per acre (*A–C*) and percentages of total yield obtained at first picking (*D–F*) from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Houston black clay, A. J. Kingfield, Dallas County, Tex.: *A*, increases in yields obtained in 1929 over average for check plots of 634 pounds per acre; *B*, increases in yields obtained in 1930 over average for check plots of 500 pounds per acre; *C*, increases in yields obtained in 1931 over average for check plots of 703 pounds per acre; *D*, percentages obtained at first picking in 1929, average for check plots 51 percent; *E*, percentages obtained at first picking in 1930, average for check plots 39 percent; *F*, percentages obtained at first picking in 1931, average for check plots 54 percent.

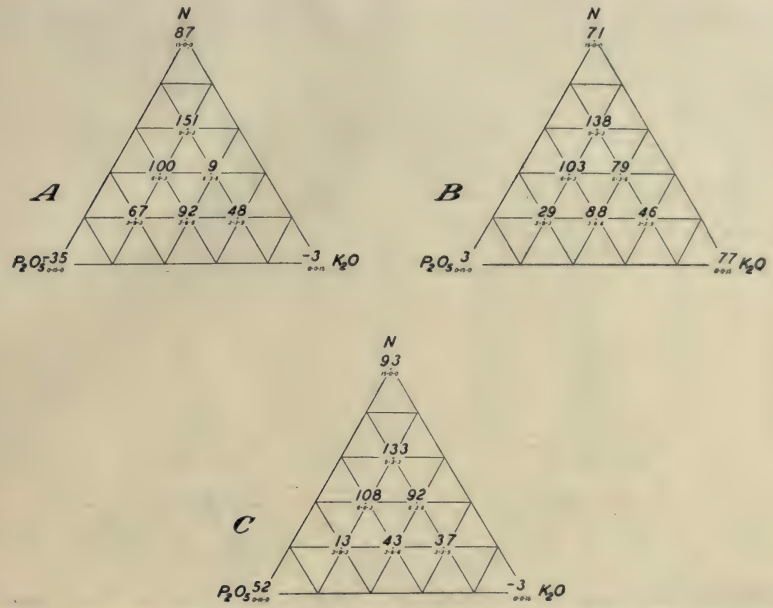

FIGURE 8.—Increases in yield of seed cotton in pounds per acre from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Houston black clay, at substation no. 5, Texas Agricultural Experiment Station, Temple, Bell County: *A*, increases in yields obtained in 1929 over average for check plots of 502 pounds per acre; *B*, increases in yields obtained in 1930 over average for check plots of 502 pounds per acre; *C*, increases in yields obtained in 1931 over average for check plots of 533 pounds per acre.

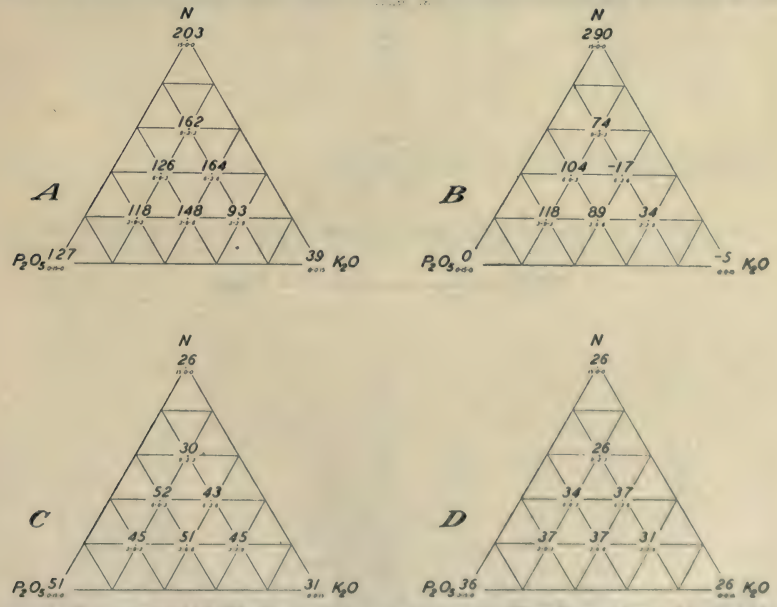

FIGURE 9.—Increases in yield of seed cotton in pounds per acre (*A–B*) and percentages of total yield obtained at first picking (*C–D*) from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Houston black clay, W. F. Voelker field, Travis County, Tex.: *A*, Increases in yields obtained in 1929 over average for check plots of 612 pounds per acre; *B*, increases in yields obtained in 1931 over average for check plots of 604 pounds per acre; *C*, percentages obtained at first picking in 1929, average for check plots 39 percent; *D*, percentages obtained at first picking in 1931, average for check plots 30 percent.

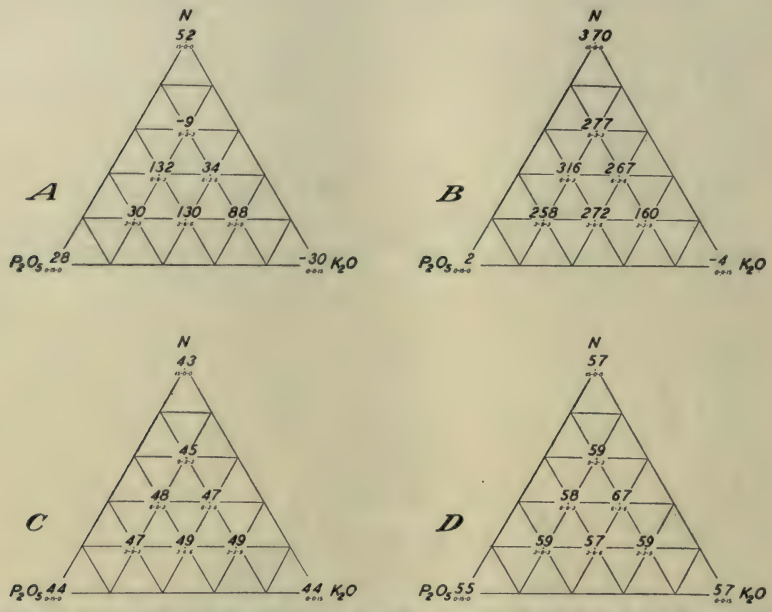

FIGURE 10.—Increases in yield of seed cotton in pounds per acre (*A–B*) and percentages of total yield obtained at first picking (*C–D*) from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Houston black clay, W. C. Blanks field, Caldwell County, Tex.: *A*, increases in yields obtained in 1930 over average for check plots of 763 pounds per acre; *B*, increases in yields obtained in 1931 over average for check plots of 695 pounds per acre; *C*, percentages obtained at first picking in 1930, average for check plots 36 percent; *D*, percentages obtained at first picking in 1931, average for check plots 50 percent.

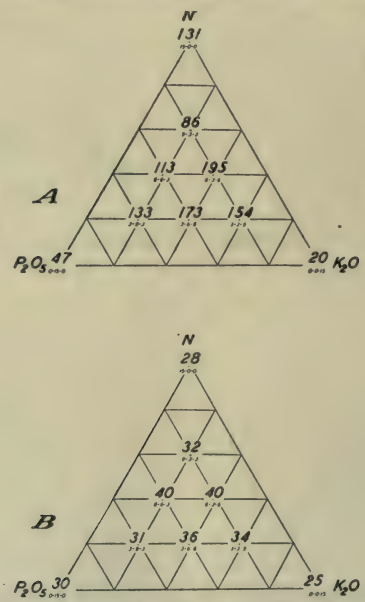

FIGURE 11.—Increases in yield of seed cotton in pounds per acre (*A*) and percentages of total yield obtained at first picking (*B*) from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Houston black clay, W. E. Jones field, Dallas County, Tex.: *A*, increases in yields obtained over average for check plots of 924 pounds per acre; *B*, percentages obtained at first picking, average for check plots 27 percent.

TABLE 2.—*Yields and increases in yield of seed cotton per acre on Houston black clay, flat phase, on A. J. King field, Dallas County, 1929–31*

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	1929				
		First picking, Aug. 28		Total		Cotton open at first picking
		Yield	Increase [1] from fertilizer	Yield	Increase [1] from fertilizer	
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Percent*
Check		193		550		35
1	0–15– 0	244	51	576	26	42
5	3– 9– 3	352	102	646	57	54
8	3– 6– 6	376	69	686	58	55
Check		307		628		49
9	6– 6– 3	419	112	696	68	60
12	3– 3– 9	391	47	654	16	60
13	6– 3– 6	459	78	729	82	63
Check		381		647		59
14	9– 3– 3	519	138	707	60	73
16	0– 0–15	397	15	688	8	58
21	15– 0– 0	528	85	752	40	70
Check		443		712		62

Plot no.	Fertilizer analyses N–P_2O_5–K_2O)	1930					1931				
		First picking, Aug. 21		Total		Cotton open at first picking	First picking, Sept. 23		Total		Cotton open at first picking
		Yield	Increase [1] from fertilizer	Yield	Increase [1] from fertilizer		Yield	Increase [1] from fertilizer	Yield	Increase [1] from fertilizer	
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Percent*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Percent*
Check		208		501		42	338		611		55
1	0–15– 0	255	47	598	97	43	432	94	761	150	57
5	3– 9– 3	340	150	667	165	51	457	113	855	226	53
8	3– 6– 6	306	135	664	161	46	453	103	816	170	56
Check		171		503		34	350		646		54
9	6– 6– 3	318	147	646	143	49	506	156	930	284	54
12	3– 3– 9	299	134	585	104	51	473	111	861	169	55
13	6– 3– 6	357	199	648	189	55	491	118	974	236	50
Check		158		459		34	373		738		51
14	9– 3– 3	312	154	671	212	46	543	170	968	230	56
16	0– 0–15	216	18	539	42	40	552	143	973	195	57
21	15– 0– 0	346	108	682	147	51	629	185	1, 160	342	54
Check		238		535		44	444		818		54

[1] Plots occur in the field in the same order as they are presented above. In calculating "increase from fertilizer" treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

TABLE 3.—*Yields and increases in yield of seed cotton per acre on Houston black clay at substation no. 5, Texas Agricultural Experiment Station, 1929–31*

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	1929			1930			1931		
		Yield of plot	Yield of adjoining check plot	Increase from fertilizer [1]	Yield of plot	Yield of adjoining check plot	Increase from fertilizer [1]	Yield of plot	Yield of adjoining check plot	Increase from fertilizer
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	0–15– 0	509	544	−35	556	553	3	664	612	52
5	3– 9– 3	594	527	67	582	553	29	629	616	13
8	3– 6– 6	571	479	92	567	479	88	623	580	43
9	6– 6– 3	581	481	100	573	470	103	533	425	108
12	3– 3– 9	548	500	48	525	479	46	510	473	37
13	6– 3– 6	509	500	9	558	479	79	565	473	92
14	9– 3– 3	632	481	151	608	470	138	558	425	133
16	0– 0–15	476	479	−3	556	479	77	577	580	−3
21	15– 0– 0	614	527	87	624	553	71	709	616	93

[1] Calculated by comparison with adjoining check plot. This experiment involved a test of varieties and planting dates in addition to the fertilizer-analyses comparison. The above data for 1929 are for 3 varieties (Lone Star, Kasch, Delfos) and 2 planting dates. The data for 1930 are for 3 varieties (Bennett, Kasch, and Delfos) and 2 planting dates. The 1931 data involve only a single variety (Qualla) and a single planting date. The table above summarizes the essential data pertaining to fertilizer effect.

TABLE 4.—*Yields and increases in yield of seed cotton per acre on Houston black clay, flat phase, on W. F. Voelker field, Travis County, 1929 and 1931*

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	1929					1931[2]				
		First picking, Aug. 19		Total		Cotton open at first picking	First picking, Aug. 18		Total		Cotton open at first picking
		Yield	Increase from fertilizer[1]	Yield	Increase from fertilizer[1]		Yield	Increase from fertilizer[1]	Yield	Increase from fertilizer[1]	
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Percent*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Percent*
Check		260		542		48	180		549		33
1	0–15– 0	344	84	669	127	51	197	17	549	00	36
8	3– 6– 6	393	103	774	148	51	241	76	652	89	37
5	3– 9– 3	369	50	827	118	45	255	106	695	118	37
Check		319		709		45	149		577		26
9	6– 6– 3	432	113	835	126	52	230	81	681	104	34
12	3– 3– 9	356	85	784	93	45	231	28	747	34	31
13	6– 3– 6	362	139	837	164	43	307	50	832	−17	37
Check		223		673		33	257		849		30
14	9– 3– 3	254	31	835	162	30	238	−19	923	74	26
16	0– 0–15	201	14	638	39	31	164	−31	639	−5	26
21	15– 0– 0	186	35	728	203	26	192	59	729	290	26
Check		151		525		29	133		439		30

[1] Plots occur in the field in the same order as they are presented above. In calculating "increase from fertilizer" treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

[2] Fertilizer placement was shallow in this experiment for 1931. It is probable that the mineral elements of the fertilizers were not fully effective for this reason (p. 13).

TABLE 5.—*Yields and increases in yield of seed cotton per acre on Houston black clay, flat phase, on W. C. Blanks field, Caldwell County, 1930–31*

Plot no.	Fertilizer analyses N–P_2O_5–K_2O)	1930					1931				
		First picking, Aug. 15		Total		Cotton open at first picking	First picking, Sept. 11		Total		Cotton open at first picking
		Yield	Increase from fertilizer[1]	Yield	Increase from fertilizer[1]		Yield	Increase from fertilizer[1]	Yield	Increase from fertilizer[1]	
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Percent*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Percent*
Check		305		840		36	372		773		48
1	0–15– 0	384	79	868	28	44	425	53	775	2	55
5	3– 9– 3	388	115	823	30	47	584	239	989	258	59
8	3– 6– 6	431	191	875	130	49	545	227	960	272	57
Check		240		745		32	318		688		46
9	6– 6– 3	419	179	877	132	48	581	263	1,004	316	58
12	3– 3– 9	405	147	831	88	49	486	156	829	160	59
13	6– 3– 6	362	86	775	34	47	617	276	917	267	67
Check		276		741		37	341		650		53
14	9– 3– 3	329	53	732	−9	45	545	204	927	277	59
16	0– 0–15	312	29	703	−30	44	372	31	655	−4	57
21	15– 0– 0	334	45	776	52	43	595	254	1,038	370	57
Check		289		724		40	341		668		51

[1] Plots occur in the field in the same order as they are presented above. In calculating "increase from fertilizer" treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

TABLE 6.—*Yields and increases in yield of seed cotton per acre on Houston black clay, on W. E. Jones field, Dallas County, 1931*

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	First picking, Sept. 1		Total		Cotton open at first picking
		Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]	
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Percent*
Check		325		1,022		32
1	0–15– 0	323	−2	1,069	47	30
5	3– 9– 3	323	60	1,051	133	31
8	3– 6– 6	358	158	986	173	36
Check		200		813		25
9	6– 6– 3	368	168	926	113	40
12	3– 3– 9	339	121	1,005	154	34
13	6– 3– 6	430	194	1,084	195	40
Check		236		889		27
14	9– 3– 3	314	78	975	86	32
16	0– 0–15	238	6	951	20	25
21	15– 0– 0	309	82	1,104	131	28
Check		227		973		23

[1] Plots occur in the field in the same order as they are presented above. In calculating "increase from fertilizer" treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

As indicated in figures 7, 8, 9, 10, and 11, the most effective fertilizer for Houston black clay has consistently been one rather high in nitrogen content. In the King and Blanks experiments for 1931 and the Voelker experiment for both years the 15–0–0 fertilizer has given the greatest increase in total yield. In all other cases, however, a fertilizer with 6 to 9 percent of nitrogen, 3 to 6 percent of available phosphoric acid, and about 3 percent of potash has given the best returns. Such a ratio has also proved well adapted, even where nitrogen alone has been most effective. A 1:1, to 3:1, ratio between nitrogen and phosphoric acid, with perhaps a small proportion of potash, is accordingly indicated.

Both phosphoric acid and nitrogen have accelerated maturity in the experiments on this soil type, with high-phosphate ratios the more effective in most instances. However, high-nitrogen ratios, such as the 9–3–3 and 15–0–0, have been very effective in this respect in all except the Voelker experiment. This is shown in figures 7, *D–E*; 9, *C*, *D*; 10, *C*, *D*; and 11, *B*. Such maturity acceleration has undoubtedly contributed to the higher yields on fertilized plots. As judged by their combined effect on maturity and yields, therefore, the high-nitrogen ratios seem best adapted.

The maximum increases in yield range from 13 percent in the King experiment in 1929 to 53 percent on the Blanks field in 1931. A cumulative effect of fertilizer is evident in the results, as shown by the generally greater response in each successive year. The maximum increases in yield on the King field in the 3 successive years were 82, 212, and 342 pounds, respectively, of seed cotton per acre. The greatest increase in yield on the Blanks experiment in 1930 was 132 pounds and in 1931 it was 370 pounds. Thus the effectiveness of a given treatment should be judged by the average results over a term of years. The effect of fertilizer on cotton plants in several fields of Houston black clay is shown in figure 12.

In the Blanks and W. E. Jones experiments there were included series of plots which received the same fertilizer ratios at 300 pounds per acre, or half the standard rate. Summaries of the results are given in tables 7 and 8, and shown graphically in figures 13 and 14, *A*, *B*.

FIGURE 12.—Effect of fertilizers on the growth of cotton on Houston black clay in Texas: *A*, Very young cotton, Range field, Dallas County, June 10, 1931, plot at left treated with 6–10–4 fertilizer at 600 pounds per acre, unfertilized plot at right; *B*, young cotton, W. E. Jones field, Dallas County, plot at left treated with 15–30–15 fertilizer at 150 pounds per acre, unfertilized plot at right; *C*, growth of cotton on W. F. Voelker field, Travis County, photographed July 17, 1930, plot at right treated with 6–6–3 fertilizer at 600 pounds per acre, unfertilized plot at left.

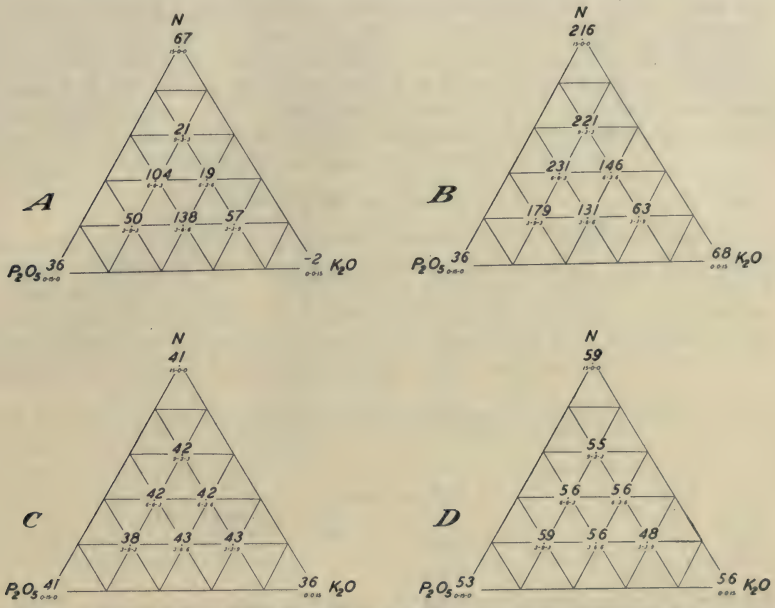

FIGURE 13.—Increases in yield of seed cotton in pounds per acre (*A–B*) and percentages of total yield obtained at first picking (*C–D*) from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Houston black clay, W. C. Blanks field, Caldwell County, Tex., using 300 pounds fertilizer per acre: *A*, increases in yields obtained in 1930 over average for check plots of 705 pounds per acre; *B*, increases in yields obtained in 1931 over average for check plots of 614 pounds per acre; *C*, percentages obtained at first picking in 1930, average for check plots 33 percent; *D*, percentages obtained at first picking in 1931, average for check plots 47 percent.

TABLE 7.—*Yields and increases in yield of seed cotton per acre on Houston black clay, flat phase, on W. C. Blanks field, Caldwell County, when fertilizers were used at the rate of 300 pounds per acre, 1930–31*

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	1930					1931				
		First picking, Aug. 15		Total		Cotton open at first picking	First picking, Sept. 11		Total		Cotton open at first picking
		Yield	Increase from fertilizer[1]	Yield	Increase from fertilizer[1]		Yield	Increase from fertilizer[1]	Yield	Increase from fertilizer[1]	
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Percent*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Percent*
Check		226		742		30	310		632		49
1	0–15– 0	319	93	778	36	41	356	46	668	36	53
5	3– 9– 3	294	68	764	50	38	472	184	799	179	59
8	3– 6– 6	354	128	824	138	43	416	151	739	131	56
Check		226		686		33	265		608		44
9	6– 6– 3	330	104	790	104	42	472	207	839	231	56
12	3– 3– 9	323	94	750	57	43	314	56	650	63	48
13	6– 3– 6	301	69	718	19	42	401	150	711	146	56
Check		232		699		33	251		565		44
14	9– 3– 3	304	72	720	21	42	436	185	786	221	55
16	0– 0–15	253	10	695	−2	36	378	82	677	68	56
21	15– 0– 0	314	60	761	67	41	512	171	868	216	59
Check		254		694		37	341		652		52

[1] Plots occur in the field in the same order as they are presented above. In calculating "increase from fertilizer" treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

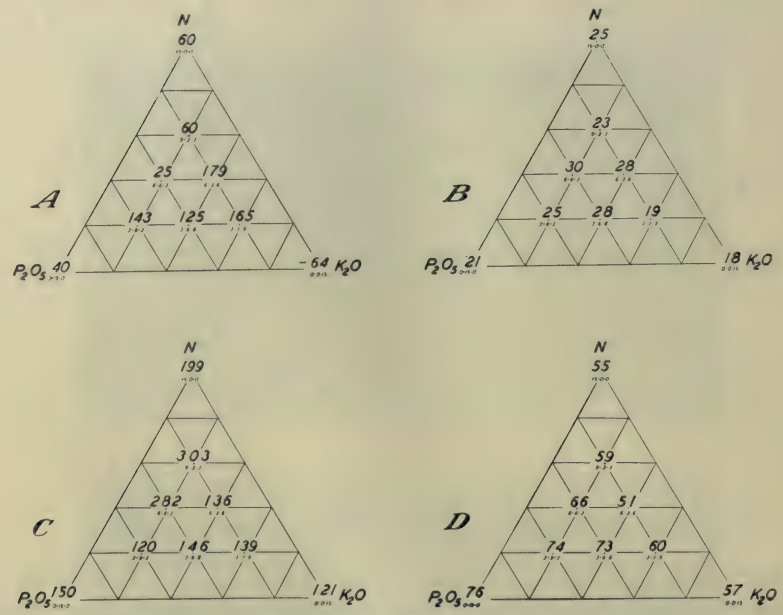

FIGURE 14.—*A*, *B*, Results from using 300 pounds of fertilizer per acre on Houston black clay, W. E. Jones field, Dallas County, 1931: *A*, increases in yield in pounds of seed cotton per acre over average yields from check plots of 971 pounds; *B*, percentages of yield obtained at first picking, average of check plots 23 percent; *C*, *D*, results from using 600 pounds of fertilizer per acre on Houston clay, J. J. Cooper field, McLennan County, 1931; *C*, increases in yield over average yield from check plots of 571 pounds; *D*, percentages of yield obtained at first picking, average of check plots 54 percent.

TABLE 8.—*Yields and increases in yield of seed cotton per acre on Houston black clay, on W. E. Jones field, Dallas County, 1931, when fertilizers were used at the rate of 300 pounds per acre*

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	First picking, Sept. 1		Total		Cotton open at first picking
		Yield	Increase from fertilizer [1]	Yield	Increase From fertilizer [1]	
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Percent*
Check		298		1,000		30
1	0–15– 0	216	−82	1,040	40	21
5	3– 9– 3	276	28	1,094	143	25
8	3– 6– 6	290	92	1,027	125	28
Check		198		902		22
9	6– 6– 3	276	78	927	25	30
12	3– 3– 9	200	31	1,078	165	19
13	6– 3– 6	305	165	1,103	179	28
Check		140		924		15
14	9– 3– 3	227	87	984	60	23
16	0– 0–15	163	−27	927	−64	18
21	15– 0– 0	280	40	1,118	60	25
Check		240		1,058		23

[1] Plots occur in the field in the same order as they are presented above. In calculating "increase from fertilizer" treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

When these data are compared with the corresponding results from fertilizers applied at 600 pounds per acre, it is seen that cotton has responded to the same ratios. On the Blanks field the magnitude of response in the two series was about equal in 1930, and only of

moderately lower order from the 300-pound rate in 1931. On the W. E. Jones field the increases in yield from the lower acre rate were only a little less than those from the higher rate. In all cases the increase per pound of fertilizer was very much in favor of the 300-pound application. In accelerating maturity the lower rate was also quite effective. These results suggest that lower acre rates than 600 pounds might be more economical on this soil type.

RESULTS ON HOUSTON CLAY

Houston clay is a brown, grayish-brown, or dark-brown clay, with a brown or yellowish-brown clay subsoil. Soil, subsoil, and the parent material are calcareous. The Cooper field in McLennan County is the only one on soil of this type; and only the 1931 results are available, as the experiment was inaugurated in that season. Yield data are presented in table 9 and shown graphically in figure 14, *C*, *D*.

TABLE 9.—*Yields and increases in yield of seed cotton per acre on Houston clay on J. J. Cooper field, McLennan County, 1931*

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	First picking, Sept. 3		Total		Cotton open at first picking
		Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]	
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Percent*
Check		269		473		57
1	0–15– 0	473	204	623	150	76
5	3– 9– 3	440	171	593	120	74
8	3– 6– 6	452	183	619	146	73
Check		269		473		57
9	6– 6– 3	499	230	755	282	66
12	3– 3– 9	423	125	701	139	60
13	6– 3– 6	398	71	787	136	51
Check		327		651		50
14	9– 3– 3	563	236	954	303	59
16	0– 0–15	447	100	791	121	57
21	15– 0– 0	484	117	887	199	55
Check		367		688		53

[1] Plots occur in the field in the same order as they are presented above. In calculating "increase from fertilizer" treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

It is evident that cotton on this field responded to a fertilizer ratio similar to those that were most effective on Houston black clay. The magnitude of response, however, was much greater. The 9:3:3 ratio gave an increase in yield of 303 pounds of seed cotton per acre, which is 53 percent of the basic yield of the field as indicated by check plots. The 6–6–3 fertilizer was nearly as effective, with an increase in yield of 282 pounds.

The results show that the degree of acceleration of maturity varied directly with the percentage of phosphoric acid in the fertilizer. Even with the 9–3–3 fertilizer, however, maturity acceleration was appreciable. Fifty-nine percent of the total crop was secured at the first picking, as against 54 percent from check plots.

RESULTS ON BELL CLAY

Bell clay is an old alluvial soil occupying a second-bottom or terrace position. The surface soil is a black, highly colloidal clay, similar to the Houston black clay in chemical and physical properties. This

grades beneath into dark-gray or brown clay. This soil differs from those of the Houston series in that the depth of the surface soil generally is greater, and especially the depth to parent material. The relief varies from flat to gently undulating. The soil is calcareous throughout the profile.

The J. W. Jones field is representative of this soil type. The experiment comprises two series of plots (designated as series 1 and 2), located at opposite ends of the same 8-acre field. Identical treatments have been used in both series. Series 1 is in an area where root rot is uniformly distributed, although in the years covered by these experi-

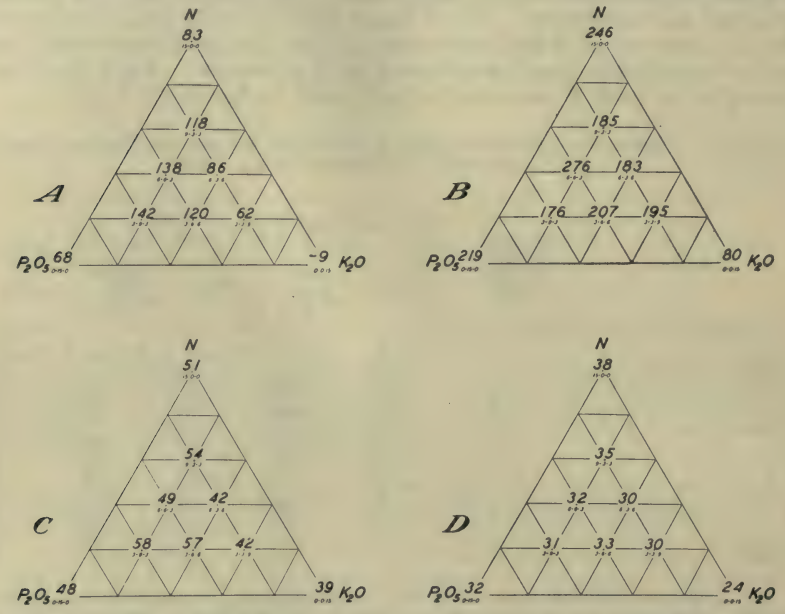

FIGURE 15.—Increases in yield of seed cotton in pounds per acre (*A–B*) and percentages of total yield obtained at first picking (*C–D*) from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Bell clay, J. W. Jones field, Dallas County, Tex.: *A*, Increases in yields obtained in 1929 over average for check plots of 516 pounds per acre; *B*, increases in yields obtained in 1931 over average for check plots of 807 pounds per acre; *C*, percentages obtained at first picking in 1929, average for check plots 31 percent; *D*, percentages obtained at first picking in 1931, average for check plots 22 percent.

ments cotton did not die appreciably until after the crop had practically matured. Series 2 is on noninfested soil. The experiment has been in progress for 3 years; but hail and insect injury to the 1930 crop made the results for that year unreliable.

The soil on which both series of plots are located responded to the same fertilizer ratios. However, the soil of series 2 proved a little more responsive in 1929 and very appreciably more so in 1931. This area has suffered a little more from erosion than the location of series 1, and this may account for the difference, at least in part. Complete data for both series are given in table 10. The essential data were averaged, and these averages are shown graphically in figure 15, which probably represents most accurately what might be expected on this soil type.

TABLE 10.—*Yields and increases in yield of seed cotton per acre on Bell clay on J. W. Jones field, Dallas County, Tex., 1929–31*

SERIES 2

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	1930					1931				
		First picking, Aug. 21		Total		Cotton open at first picking	First picking, Sept. 2		Total		Cotton open at first picking
		Yield	Increase from fertilizer[1]	Yield	Increase from fertilizer[1]		Yield	Increase from fertilizer[1]	Yield	Increase from fertilizer[1]	
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Percent*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Percent*
1	0–15– 0	275	39	559	69	49	346	178	1,150	305	30
Check		236		490		48	168		845		20
5	3– 9– 3	395	159	602	112	66	285	117	1,083	238	26
8	3– 6– 6	408	225	595	142	69	231	114	980	293	24
9	6– 6– 3	381	252	614	198	62	245	180	964	435	25
Check		129		416		31	65		529		12
12	3– 3– 9	300	171	511	95	59	240	175	850	321	28
13	6– 3– 6	314	204	532	117	59	213	134	836	263	25
14	9– 3– 3	205	114	562	149	36	240	148	860	243	28
Check		91		413		22	92		617		15
16	0– 0–15	111	20	414	1	27	123	31	716	99	17
21	15– 0– 0	250	159	566	153	44	314	222	954	337	33

SERIES 1

Check		201		608		33	318		975		33
1	0–15– 0	315	114	675	67	47	365	47	1,108	133	33
5	3– 9– 3	386	215	775	172	50	399	113	1,097	114	36
8	3– 6– 6	307	166	696	98	44	469	216	1,112	121	42
Check		141		598		24	253		991		26
9	6– 6– 3	239	98	675	77	35	417	164	1,108	117	38
12	3– 3– 9	151	42	630	28	24	344	91	1,063	69	32
13	6– 3– 6	156	80	660	55	24	385	132	1,100	103	35
Check		76		605		13	253		997		25
Check		285		651		44	303		906		33
14	9– 3– 3	522	237	738	87	71	424	121	1,033	127	41
16	0– 0–15	284	82	555	−19	51	282	35	955	60	30
21	15– 0– 0	290	172	510	13	57	446	256	1,037	154	43
Check		118		497		24	190		883		22

AVERAGE

1	0–15– 0		77		68	48		113		219	32
5	3– 9– 3		187		142	58		115		176	31
8	3– 6– 6		196		120	57		165		207	33
9	6– 6– 3		175		138	49		172		276	32
12	3– 3– 9		107		62	42		133		195	30
13	6– 3– 6		142		86	42		133		183	30
14	9– 3– 3		176		118	54		135		185	35
16	0– 0–15		51		−9	39		33		80	24
21	15– 0– 0		166		83	51		239		246	38

[1] Plots occur in the field in the same order as they are presented above. In calculating "increase from fertilizer" treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

There is a tendency for the results on Bell clay to show two major peaks in response as indicated in figure 15, *A*, *B*. High-nitrogen fertilizers have given excellent returns, especially in 1931. The other peak, and in general the more favorable response, has been obtained with a fertilizer containing 3 to 6 percent of nitrogen and 6 to 9 percent of available phosphoric acid. The importance of potash is difficult to establish where only the nine ratios are included, but indications are that it is small. Accordingly a 1 : 3 : 1 or a 2 : 2 : 1 ratio of nitrogen, phosphoric acid, and potash seems best adapted.

An appreciable acceleration of maturity resulted from all fertilizers containing either nitrogen or phosphoric acid alone, or the two in combination. This is shown in figure 15, *C*, *D*. The 3–9–3 analysis gave 58 percent of the total crop at first picking in 1929,

FIGURE 16.—*A*, Effect of fertilizer on early growth of cotton on Bell clay, J. W. Jones field, Dallas County, Tex.; plot at left treated with 3–9–3 fertilizer at 600 pounds per acre; unfertilized plot at right, photographed June 20, 1931. *B*, Effect of fertilizer on the maturity of cotton; rows at left treated with 6–6–3 fertilizer at 600 pounds per acre had an average of 3 times as many mature bolls as the unfertilized rows at the right; leaves plucked in foreground to show open bolls; photographed at date of first picking August 21, 1929. *C*, Effect of fertilizer on early yield. Cotton at left picked from plot treated with 6–6–3 fertilizer yielded at the rate of 381 pounds of seed cotton per acre at first picking on August 21, 1929; cotton at right picked on same date from unfertilized plot yielded at the rate of 129 pounds per acre.

as opposed to 31 percent for the checks. Corresponding figures in 1931 were 31 and 22 percent, respectively. Potash alone accelerated maturity in 1929.

The effects of fertilizer on early growths of cotton, on early maturity, and on yield on Bell clay, are shown in figure 16.

RESULTS ON WILSON CLAY

The surface soil of Wilson clay is dark-gray to nearly black, stiff, heavy clay. Beneath the surface horizon is dark-gray clay; and the substratum below 3 to 5 feet is calcareous clay or marl, light gray to brownish yellow in color. Soil and subsoil are noncalcareous. In small areas the lower subsoil approaches the surface.

The United States Cotton Breeding Field Station at Greenville, Hunt County, is on soil of this type. Four years' data from the experiments conducted here are presented in table 11 and figures 17 and 18.

TABLE 11.—*Yields and increases in yield of seed cotton per acre on Wilson clay at United States Cotton Breeding Field Station, Hunt County, 1928–31*

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	1928, total		1929				
				First picking, Aug. 26		Total		Cotton open at first picking
		Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]	
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Percent*
Check		494		137		571		24
1	0–15– 0	515	21	109	−28	553	−18	20
5	3– 9– 3	591	71	166	35	626	57	27
8	3– 6– 6	557	12	163	38	640	74	25
Check		545		125		566		22
9	6– 6– 3	568	23	176	51	659	93	27
12	3– 3– 9	581	66	168	37	628	60	27
13	6– 3– 6	613	128	192	55	671	101	29
Check		485		137		570		24
14	9– 3– 3	602	117	182	45	678	108	27
16	0– 0–15	535	48	127	−8	609	34	21
21	15– 0– 0	548	60	144	12	680	101	21
Check		488		132		579		23

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	1930					1931				
		First picking, Aug. 26		Total		Cotton open at first picking	First picking, Sept. 11		Total		Cotton open at first picking
		Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]		Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]	
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Percent*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Percent*
Check		294		548		54	294		960		31
1	0–15– 0	336	42	563	15	60	375	81	937	−23	40
5	3– 9– 3	404	119	662	120	61	457	135	1,040	82	44
8	3– 6– 6	391	116	650	114	60	452	103	1,045	89	43
Check		275		536		51	349		956		37
9	6– 6– 3	410	135	687	151	60	410	61	1,125	169	36
12	3– 3– 9	398	120	635	109	63	352	34	1,046	127	34
13	6– 3– 6	401	121	651	136	62	350	63	1,086	204	32
Check		280		515		54	287		882		33
14	9– 3– 3	389	109	661	146	59	379	92	1,129	247	34
16	0– 0–15	312	32	549	34	57	302	15	938	56	32
21	15– 0– 0	322	42	566	51	57	310	23	1,069	187	29

[1] Plots occur in the field in the same order as they are presented above. In calculating "increase from fertilizer" treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

The most effective fertilizer for this soil is one with from 6 to 9 percent of nitrogen, 3 to 6 percent of available phosphoric acid, and about 3 percent of potash, as will be noted in figure 17. Maximum

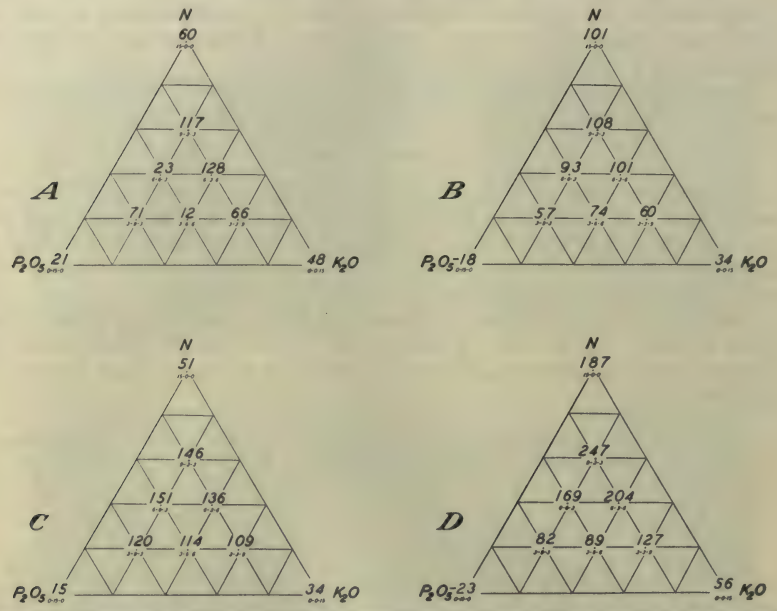

FIGURE 17.—Increases in yield of seed cotton in pounds per acre from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Wilson clay, United States Cotton Breeding Field Station, Greenville, Tex.: *A*, Increases in yields obtained in 1928 over average for check plots of 503 pounds per acre; *B*, increases in yields obtained in 1929 over average for check plots of 572 pounds per acre; *C*, increases in yields obtained in 1930 over average for check plots of 533 pounds per acre; *D*, increases in yields obtained in 1931 over average for check plots of 933 pounds per acre.

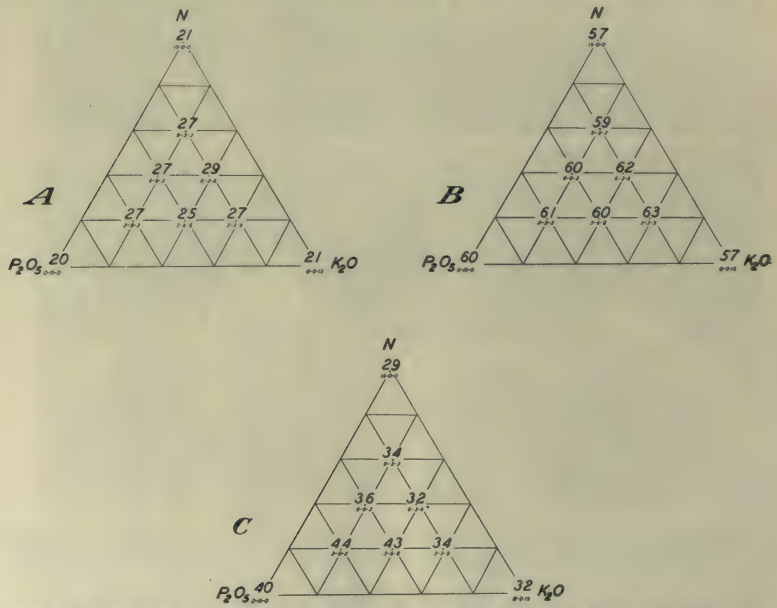

FIGURE 18.—Percentages of total yield of seed cotton obtained at first picking from use of fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Wilson clay, United States Cotton Breeding Field Station, Greenville, Tex.: *A*, Percentages obtained at first picking in 1929, average for check plots 23 percent; *B*, percentages obtained at first picking in 1930, average for check plots 53 percent; *C*, percentages obtained at first picking in 1931, average for check plots 34 percent.

FIGURE 19.—Effect of fertilizers on the growth and yield of cotton on Wilson clay, United States Cotton Breeding Field Station, Greenville, Tex.: *A*, Very young cotton, plot at left treated with 15–0–0 fertilizer at 600 pounds per acre but without visible response, and plot at right treated with 15–30–15 fertilizer at 150 pounds per acre, photographed June 7, 1930; *B*, plot at left treated with 9–3–3 fertilizer at 600 pounds per acre, and plot at right treated with 0–0–15 fertilizer and comparable to unfertilized plots, photographed July 17, 1929; *C*, rows at left treated with 6–6–3 fertilizer at 600 pounds per acre, rows at right unfertilized, leaves plucked in foreground to show open bolls September 27, 1928.

increases in yield varying from 108 pounds of seed cotton per acre in 1929 to 247 pounds in 1931 were obtained from such ratios applied at the rate of 600 pounds per acre.

Data showing the effect of fertilizers on maturity acceleration are lacking for 1928. In the 3 years for which data are shown in figure 18 practically all combinations of nitrogen and phosphoric acid were effective in this respect.

The effects of fertilizers on early growth of young cotton, on growth in midseason, and on yield on Wilson clay are shown in figure 19.

RESULTS ON WILSON CLAY LOAM

The surface soil of Wilson clay loam is a dark-gray to dark-brown, noncalcareous clay loam. Below 6 or 8 inches this grades into stiff

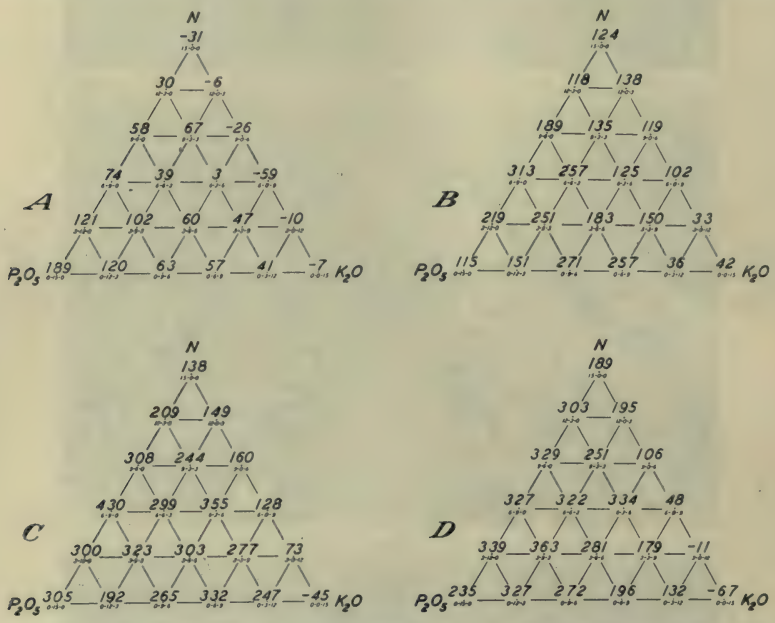

FIGURE 26.—Increases in yield of seed cotton in pounds per acre from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Wilson clay loam, R. W. Craig field, Hunt County, Tex.: *A*, Increases in yields obtained in 1928 over average for check plots of 279 pounds per acre; *B*, increases in yields obtained in 1929 over average for check plots of 454 pounds per acre; *C*, increases in yields obtained in 1930 over average for check plots of 369 pounds per acre; *D*, increases in yields obtained in 1931 over average for check plots of 343 pounds per acre.

brown to grayish-brown clay. The subsoil is yellowish-brown clay, calcareous and filled with concretions of calcium carbonate. The soil mantle in the Craig field, which is representative of this type, is of variable thickness. The subsoil lies at the immediate surface in bands extending diagonally across the field. Between, in areas of deeper soil, it lies at a depth exceeding 3 feet. This soil condition with its effect upon the distribution of the root disease is to be made the subject of a separate paper.

Four years' results of experiments on the Craig field are summarized in table 12, and are shown graphically in figures 20 and 21.

TABLE 12.—*Yields and increases in yield of seed cotton per acre on Wilson clay loam, on R. W. Craig field, Hunt County, 1928–31*

Plot no.	Fertilizer analyses (N-P_2O_5-K_2O	1928					1929					1930					1931				
		First picking, Sept. 12		Total		Cotton open at first picking	First picking, Aug. 27		Total		Cotton open at first picking	First picking, Aug. 19		Total		Cotton open at first picking	First picking, Aug. 25		Total		Cotton open at first picking
		Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]		Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]		Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]		Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]	
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Pct.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Pct.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Pct.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Pct.*
Check		130		295		44	159		610		26	125		382		33	61		353		17
1	0–15– 0	224	94	484	189	46	332	173	725	115	46	283	158	687	305	41	126	65	588	235	21
2	0–12– 3	196	86	407	120	48	322	179	679	151	47	284	159	574	192	49	189	128	680	327	28
3	3–12– 0	198	108	399	121	50	247	121	664	219	37	322	197	682	300	47	165	104	692	339	24
Check		90		278		32	126		445		28	125		382		33	61		353		17
4	0– 9– 6	140	50	341	63	41	298	172	716	271	42	306	181	647	265	47	211	150	625	272	34
5	3– 9– 3	176	81	376	102	47	277	161	682	251	41	332	221	669	323	50	244	183	716	363	34
6	6– 9– 0	155	56	344	74	45	284	179	730	313	39	348	251	739	430	47	237	176	680	327	35
Check		99		270		37	105		417		25	97		309		31	61		353		17
7	0– 6– 9	142	43	327	57	43	214	109	674	257	32	242	145	641	332	38	148	87	549	196	27
8	3– 6– 6	138	42	344	60	40	227	120	607	183	37	286	198	627	303	46	191	130	634	281	30
9	6– 6– 3	133	41	336	39	40	258	150	688	257	38	260	181	638	299	41	211	150	675	322	31
Check		92		297		31	108		431		25	79		339		23	61		353		17
10	9– 6– 0	156	64	355	58	44	201	93	620	189	32	257	178	647	308	40	242	181	682	329	35
11	0– 3–12	100	11	322	41	31	139	37	474	36	29	217	137	581	247	37	155	96	455	132	34
12	3– 3– 9	118	33	311	47	38	177	82	594	150	30	224	143	605	277	37	162	106	472	179	34
Check		85		264		32	95		444		21	81		328		25	56		293		19
13	6– 3– 6	99	14	267	3	37	172	77	569	125	30	229	148	683	355	34	143	87	627	334	23
14	9– 3– 3	131	50	322	67	41	159	58	589	135	27	194	121	619	244	31	114	58	566	251	20
15	12– 3– 0	114	37	275	30	41	140	34	582	118	24	181	116	631	209	29	133	77	639	303	21
Check		77		245		31	106		464		23	65		422		15	56		336		17
16	0– 0–15	66	−11	238	−7	28	92	−14	506	42	18	59	−6	377	−45	16	39	−17	269	−67	14
17	3– 0–12	82	−3	261	−10	31	85	−17	482	33	18	78	10	477	73	16	51	−11	324	−11	16
18	6– 0– 9	73	−19	238	−59	31	85	−12	535	102	16	113	43	513	128	22	70	2	382	48	18
Check		92		297		31	97		433		22	70		385		18	68		334		20
19	9– 0– 6	91	−1	271	−26	34	99	2	552	119	18	110	40	545	160	20	73	5	440	106	17
20	12– 0– 3	103	1	287	−6	36	87	−1	550	138	16	103	25	545	149	19	92	25	547	195	17
21	15– 0– 0	99	−12	258	−31	38	81	2	515	124	16	90	4	545	138	17	85	20	559	189	15
Check		111		289		38	79		391		20	86		407		21	65		370		18

[1] Plots occur in the field in the same order as they are presented above. In calculating "increase from fertilizer" treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

It is apparent from figure 20 that the maximum increase in yield in 1928 was obtained from the 0–15–0 fertilizer. In 1929 and 1930 the most effective ratio was the 6–9–0, and in 1931 the 3–9–3. Evidently cotton on this soil responds chiefly to phosphoric acid, but the presence of some nitrogen, and perhaps a small proportion of potash, in the fertilizer increases its effectiveness. Accordingly, the need for a fertilizer having a 2:3:1 or 2:3:0 ratio of nitrogen, phosphoric acid, and potash is indicated.

The acceleration of maturity by fertilizers has been very marked, as shown in figure 21. The ratio most effective in increasing yields has also been very effective in this respect.

Wilson clay loam is the most responsive soil included in these experiments. The increase due to the most effective fertilizer was for

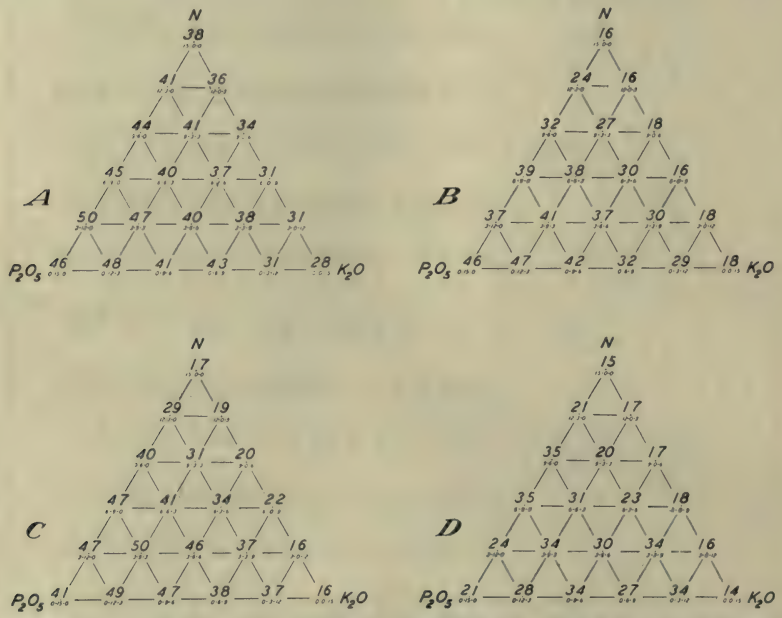

FIGURE 21.—Percentages of total yield of seed cotton obtained at first picking from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Wilson clay loam, R. W. Craig field, Hunt County, Tex.: *A*, Percentages obtained at first picking in 1928, average for check plots 35 percent; *B*, percentages obtained at first picking in 1929, average for check plots 24 percent; *C*, percentages obtained at first picking in 1930, average for check plots 25 percent; *D*, percentages obtained at first picking in 1931, average for check plots 18 percent.

1928, 68 percent; for 1929, 69 percent; for 1930, 117 percent; and for 1931, 106 percent. Incidentally 1930, when the maximum increase in yield was obtained, was the most unfavorable year for fertilizer response of the four. Conditions approaching drought prevailed throughout most of the summer.

The effect of fertilizers on growth, maturity, and yield of cotton on Wilson clay loam is shown in figure 22.

RESULTS ON IRVING CLAY

Soils of the Irving series are the terrace correlatives of the Wilson soils. The Irving clay resembles the Wilson clay closely, differing

FIGURE 22.—Effect of fertilizers on the growth, maturity, and yield of cotton on Wilson clay loam, R. W. Craig field, Hunt County, Tex.: *A*, Young cotton, the two rows at left of middle treated with 6–9–0 fertilizer at 600 pounds per acre, the two rows at right of middle unfertilized, photographed June 25, 1930; *B*, cotton, the four rows at left of middle unfertilized, the four rows at right of middle treated with 15–30–15 and 11–48–0 fertilizers at 150 pounds per acre, photographed August 19, 1930; *C*, maturity and yield of cotton, rows at left treated with 15–30–15 fertilizer at 150 pounds per acre, rows at right unfertilized, leaves plucked in foreground to show open bolls August 19, 1930.

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from it principally in position and in its greater depth to soil-forming material. Soil and subsoil are noncalcareous.

The Oscar Nelson field is representative of this soil. The field is not infested with root rot, and the results are considered as those of a

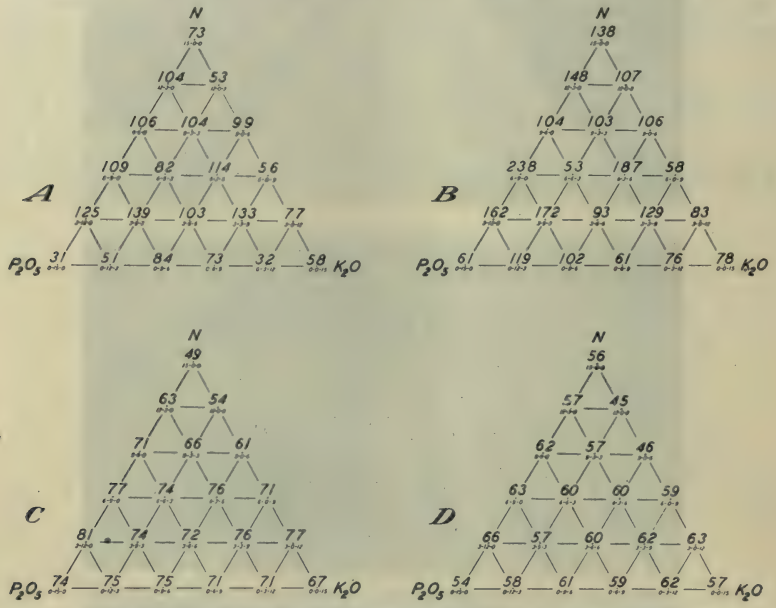

FIGURE 23.—Increases in yield of seed cotton in pounds per acre (*A–B*) and percentages of total yield obtained at first picking (*C–D*) from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Irving clay, O. Nelson field, Williamson County, Tex.: *A*, Increases in yields obtained in 1930 over average for check plots of 592 pounds per acre; *B*, increases in yields obtained in 1931 over average for check plots of 511 pounds per acre; *C*, percentages obtained at first picking in 1930, average for check plots 67 percent; *D*, percentages obtained at first picking in 1931, average for check plots 57 percent.

fertilizer-ratio test, in which experimental complications arising from root rot are eliminated. However, not all areas of this soil type are free from root rot, and these results could probably at least be duplicated in infested fields. Data for 1930 and 1931[11] are presented in table 13 and shown graphically in figure 23.

[11] The results for 1929 are unreliable as a result of a severe and irregular infestation by bollworms.

TABLE 13.—*Yields and increases in yield of seed cotton per acre on Irving clay on O. Nelson field, Williamson County, 1930–31*

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	1930					1931				
		First picking, Aug. 18		Total		Cotton open at first picking	First picking, Aug. 31		Total		Cotton open at first picking
		Yield	Increase from fertilizer[1]	Yield	Increase from fertilizer[1]		Yield	Increase from fertilizer[1]	Yield	Increase from fertilizer[1]	
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Percent*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Percent*
Check		477		639		75	310		547		57
1	0–15– 0	496	19	670	31	74	327	17	608	61	54
2	0–12– 3	494	51	658	51	75	366	55	634	119	58
3	3–12– 0	569	160	699	125	81	424	112	644	162	66
Check		409		574		71	312		482		65
4	0– 9– 6	491	82	658	84	75	356	44	584	102	61
5	3– 9– 3	537	134	726	139	74	366	80	647	172	57
6	6– 9– 0	547	150	709	109	77	446	187	705	238	63
Check		397		600		66	259		467		55
7	0– 6– 9	479	82	673	73	71	310	51	528	61	59
8	3– 6– 6	499	105	690	103	72	344	68	574	93	60
9	6– 6– 3	484	94	656	82	74	327	34	547	53	60
Check		390		574		68	293		494		59
10	9– 6– 0	484	94	680	106	71	373	80	598	104	62
11	0– 3–12	428	50	605	32	71	349	82	559	76	62
12	3– 3– 9	532	167	704	133	76	375	135	601	129	62
Check		365		571		64	240		472		51
13	6– 3– 6	520	155	685	114	76	395	155	659	187	60
14	9– 3– 3	448	69	680	104	66	334	70	581	103	57
15	12– 3– 0	431	39	685	104	63	363	75	632	148	57
Check		392		581		68	288		484		60
16	0– 0–15	431	39	639	58	67	322	34	562	78	57
17	3– 0–12	523	94	682	77	77	395	59	627	83	63
18	6– 0– 9	486	21	685	56	71	390	7	661	58	59
Check		465		629		74	383		603		64
Check		344		603		57	252		516		49
19	9– 0– 6	431	87	702	99	61	288	36	622	106	46
20	12– 0– 3	341	10	634	53	54	286	8	630	107	45
21	15– 0– 0	312	−5	632	73	49	375	72	668	138	56
Check		317		559		57	303		530		57

[1] Plots occur in the field in the same order as they are presented above. In calculating "increase from fertilizer" treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

It is evident from figure 23, *A*, *B* that cotton on this soil responds to fertilizers high in phosphoric acid. Some nitrogen seems essential to maximum response, and perhaps a small percentage of potash. The 3–9–3 mixture was most effective in 1930 and the 6–9–0 mixture in 1931. Accordingly a 1:3:1, 2:3:0 or 2:3:1 ratio is indicated. The maximum increase in yield in 1930 amounted to 23 percent and in 1931 to 47 percent.

Fertilizers high in phosphoric acid have accelerated the maturity of the crop. This is not reflected in final yields to the degree that would obtain if root rot were prevalent, however. The effect of fertilizers on growth of young cotton on Irving clay and on maturity and yield are shown in figure 24.

RESULTS ON DENTON CLAY

Denton clay is an important soil of the Grand Prairie section, which lies to the west of the black-land prairies, and in portions of which root rot is a serious problem. The surface soil is a brown to dark-brown friable clay. The subsoil is also a friable clay, but varies to yellowish brown in color. In the experiment field (Peterson) representing this type the substratum is encountered below 30 inches, and

FIGURE 24.—Effect of fertilizers on growth, maturity, and yield of cotton on Irving clay, O. Nelson field, Williamson County, Tex.: *A*, Very young cotton, rows at left treated with 6–10–4 fertilizer at 600 pounds per acre, those at right unfertilized, photographed June 8, 1929; *B*, young cotton, rows at left unfertilized, rows at right treated with 6–10–4 fertilizer at 600 pounds per acre, photographed June 25, 1929; *C*, maturity and yield of cotton, plot at left unfertilized, plot at right treated with 6–10–4 fertilizer at 600 pounds per acre, leaves plucked in foreground to show open bolls August 18, 1930.

is pale-yellow to white chalky clay loam. Soil, subsoil, and substratum are calcareous.

Three years' results from the Peterson experiment are given in table 14 and are shown graphically in figures 25 and 26.

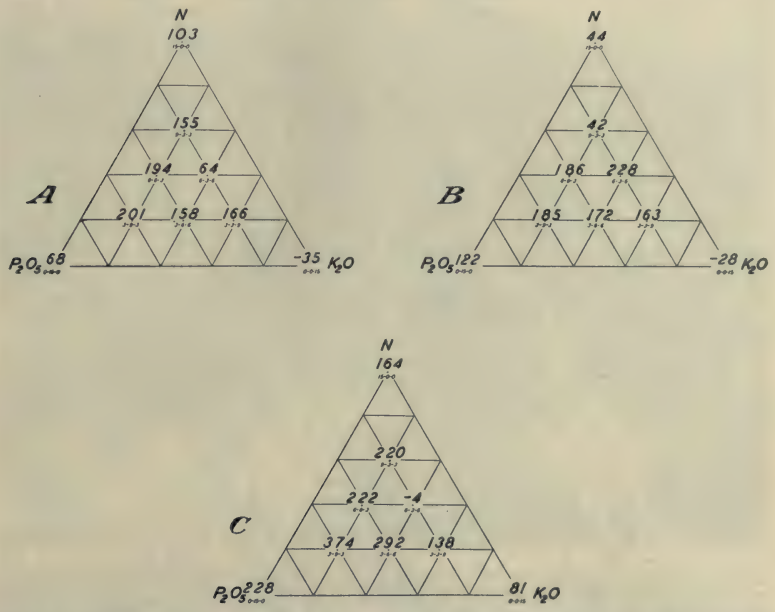

FIGURE 25.—Increases in yield of seed cotton in pounds per acre from fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Denton clay, Albert Peterson field, Williamson County, Tex.: *A*, Increases in yields obtained in 1929 over average for check plots of 244 pounds per acre; *B*, increases in yields obtained in 1930 over average for check plots of 473 pounds per acre; *C*, increases in yields obtained in 1931 over average for check plots of 508 pounds per acre.

TABLE 14.—*Yields and increases in yield of seed cotton per acre on Denton clay on Albert Peterson field, Williamson County, 1929–31*

Plot no.	Fertilizer analyses N–P_2O_5–K_2O	1929, total		1930				
				First picking, Aug. 19		Total		Cotton open at first picking
		Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]	
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Percent*
1	0–15– 0	309	68	382	129	522	122	73
5	3– 9– 3	442	201	445	192	585	185	76
8	3– 6– 6	399	158	396	143	572	172	69
Check [2]		241		253		400		63
9	6– 6– 3	435	194	396	143	586	186	68
12	3– 3– 9	407	166	378	125	563	163	67
13	6– 3– 6	305	64	388	135	628	228	62
14	9– 3– 3	402	155	437	113	587	42	74
16	0– 0–15	212	−35	375	51	517	−28	73
21	15– 0– 0	50	103	397	73	589	44	67
Check [2]		247		324		545		59

[1] Plots in this experiment are in 2 tiers. Because of arrangement the "increase from fertilizer" in each tier was calculated from the average yield of check plots in that tier.

[2] Average of 2.

TABLE 14.—*Yields and increase in yield of seed cotton per acre on Denton clay on Albert Peterson field, Williamson County, 1929–31*—Continued

Plot no.	Fertilizer analyses N–P_2O_5–K_2O	1931				
		First picking Aug. 23		Total		Cotton open at first picking
		Yield	Increase from fertilizer [1]	Yield	Increase from fertilizer [1]	
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Percent*
1	0–15– 0	262	90	694	228	38
5	3– 9– 3	342	170	840	374	41
8	3– 6– 6	303	131	758	292	40
Check [2]		172		466		37
9	6– 6– 3	274	102	688	222	40
12	3– 3– 9	212	40	604	138	35
13	6– 3– 6	162	−10	462	−4	35
14	9– 3– 3	373	209	769	220	49
16	0– 0–15	311	147	630	81	49
21	15– 0– 0	281	117	713	164	39
Check [2]		164		549		30

[1] Plots in this experiment are in 2 tiers. Because of arrangement the "increase from fertilizer" in each tier was calculated from the average yield of check plots in that tier.
[2] Average of 2.

From the data in figure 25 it is apparent that this soil responds to applications of both phosphoric acid and nitrogen. Maximum returns, however, are obtained only when the two are in combination. Response to potash alone is clearly negligible, although its importance in the fertilizer ratio is difficult to establish with the data from only nine ratios at hand. In 2 of the 3 years the 3–9–3 fertilizer gave the greatest increase in yield; and in 1930 also this treatment was among the most effective. A 1:3:1 ratio of nitrogen, phosphoric acid, and potash is accordingly indicated. This ratio was also highly effective in accelerating maturity, as shown in figure 26. Data of this kind were not obtained for the 1929 crop.

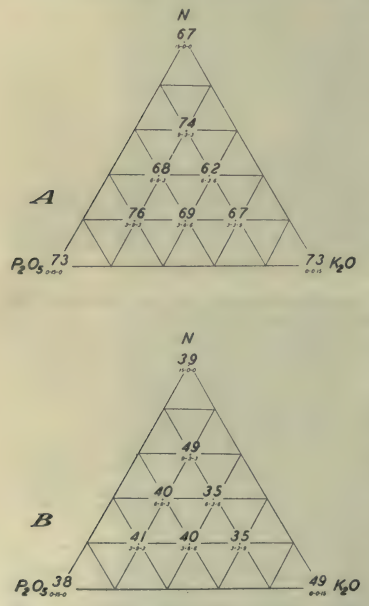

FIGURE 26.—Percentages of total yield of cotton obtained at first picking from use of fertilizers containing various ratios of nitrogen, phosphoric acid, and potash, on Denton clay, Albert Peterson field, Williamson County, Tex.: *A*, Percentages obtained at first picking in 1930, average for check plots 61 percent; *B*, percentages obtained at first picking in 1931, average for check plots 34 percent.

The effect of fertilizers on the growth, maturity, and yield of cotton on Denton clay, and the response of young cotton to nitrogen are shown in figures 27 and 29, *A*.

RESULTS ON MILLER SILTY CLAY LOAM

Miller silty clay loam is an alluvial soil, which, with related types, covers a rather extensive area in the Brazos River Valley. The experiment field, on the Earle farm in McLennan County, represents a heavy subsoil phase of this soil type. At the surface is a brown silty clay loam, and the subsoil is a brown to dark-brown clay loam.

The experiment field, like most other areas of this type, is occasionally subject to overflow.

Experiments were conducted in 1929, 1930, and 1931. The field used in 1929 had been in alfalfa during the 2 preceding years. The

FIGURE 27.—Effect of fertilizers on the growth and early yield of cotton on Denton clay, Albert Peterson field, Williamson County, Tex.: *A*, Plot at left treated with 6–6–3 fertilizer at 600 pounds per acre, plot at right unfertilized, photographed July 10, 1930; *B*, early yield of cotton, rows at left of middle treated with 9–3–3 fertilizer at 600 pounds per acre, rows at right unfertilized, leaves plucked in foreground to show open bolls August 29, 1929.

same nine fertilizers used in other experiments were applied. No consistent increases in yield were obtained.

In 1930 and 1931 a field was used which had been almost continuously in cotton for 20 years. The cotton responded to high-nitrogen

ratios, as indicated by greater vegetative growth and darker green color. However, this was not consistently translated into increased

FIGURE 28.—*A*, Effect of concentrated fertilizer on the early growth of cotton on Houston black clay, W. E. Jones field, Dallas County, Tex.; rows at left treated with commercial 15–30–15 fertilizer at 75 pounds per acre, rows at right unfertilized, photographed June 20, 1931; *B*, effect of fertilizer prepared from concentrated materials on the growth of young cotton on Wilson clay loam, R. W. Craig field, Hunt County, Tex.; plot at left treated with 6–10–4 fertilizer, compounded largely from potassium-ammonium phosphate, at 450 pounds per acre, plot at right unfertilized. Photographed June 25, 1930.

yields, although fertilizers did to a limited extent accelerate maturity. Indications are that this soil type is among the least responsive of those covered by these experiments.

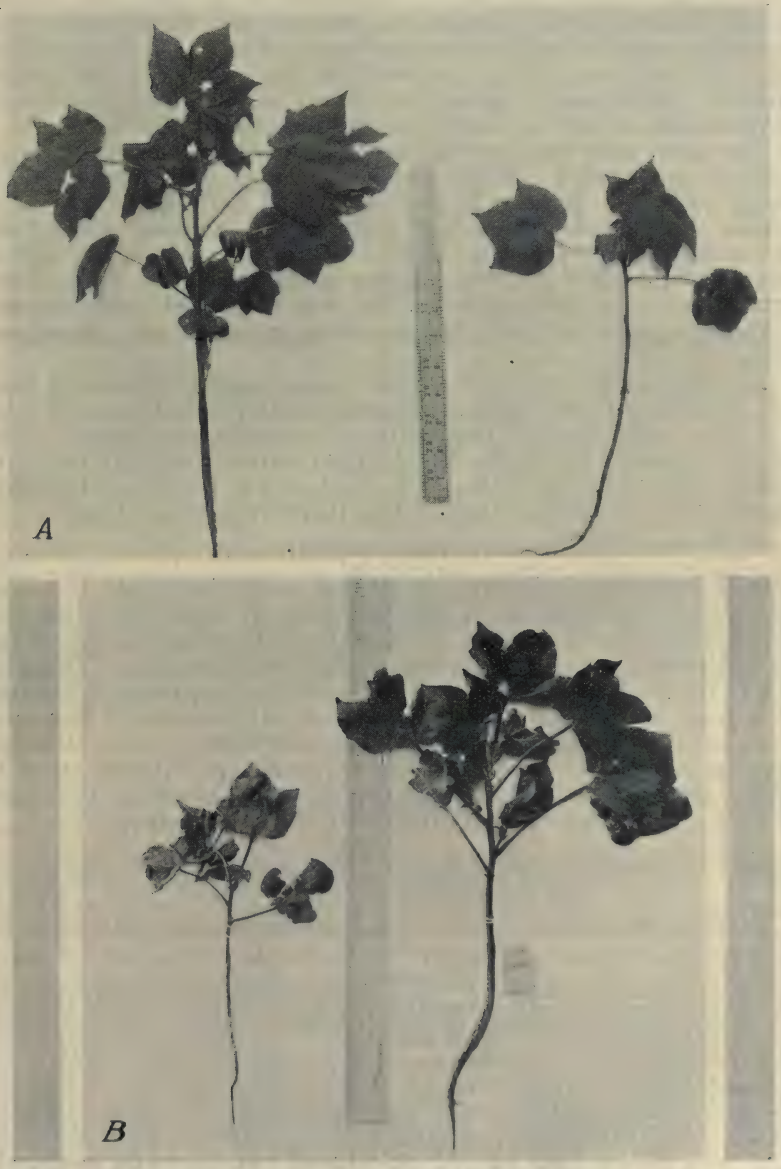

FIGURE 29.—*A*, Response of young cotton to nitrogen fertilizer on Denton clay, Albert Peterson field, Williamson County, Tex.; at left, representative plant from plot treated with 15–0–0 fertilizer at 600 pounds per acre; at right, representative plant from unferti ized plot, photographed June 14, 1929. *B*, Effect of concentrated fertilizer on the growth of young cotton on Wilson clay, United States Cotton Breeding Field Station, Greenville, Tex.; at left, representative plant from an unfertilized plot, at right, representative plant from plot treated with 15–30–15 fertilizer at 150 pounds per acre. Photographed June 7, 1930.

EXPERIMENTS AT THE UNITED STATES FIELD STATION, SAN ANTONIO

Experiments have been in progress at the United States field station of the Bureau of Plant Industry at San Antonio, for 3 years. The prevailing soil type is Houston clay loam. The soil differs from the other Houston soils, here described, in the texture of the surface horizon. Furthermore, having developed in a distinctly subhumid environment, it is less leached of mineral and organic plant food.

The same nine fertilizer ratios used in other experiments were applied to this field. Yields data are lacking for 1929 and 1931, owing to severe damage by bollweevil and bollworm. The 1930 figures do not show a consistent trend toward increased yields from any ratio. Little or no effect of fertilizer could be seen in the vegetative development of the crop in either of the two earlier years of the experiments. In 1931, however, the cotton showed small, though definite, response to fertilizers combining nitrogen and phosphoric acid.

The high native fertility of soils developed in areas of deficient rainfall, together with the limitations imposed on crop production by such a climate, make this field distinct from the others here treated. The annual precipitation on the San Antonio station was 29.45 inches in 1929, 23.93 inches in 1930, and 29.39 inches in 1931. Probably moisture was the limiting factor rather than available plant food.

RESIDUAL EFFECTS OF FERTILIZERS

In all of these experiments, except that on the Earle field, the same treatments were applied to identical plots in successive years. A study of the data shows that the magnitude of reponse on most of the soils increases in general with each successive application. That this is due to the residual effect of the fertilizer seems evident, because of a total lack of correlation with seasonal conditions. Response from fertilizer was generally greater in 1930 than in 1929, although seasonal conditions were much less favorable for fertilizer effect in 1930. Correspondingly, response was generally greater in 1931 than in 1930. Data showing such effects are represented in table 15.

TABLE 15.—*Increases in yield of seed cotton per acre from fertilizers on several soil types, showing progressive cumulative effect*

MAXIMUM INCREASES IN YIELD FROM OPTIMUM FERTILIZER EACH YEAR

Year	Houston black clay, King field		Houston black clay, Voelker field		Wilson clay, United States Cotton Breeding Station		Wilson clay loam, Craig field		Bell clay, J. W. Jones field		Irving clay, O. Nelson field		Denton clay, Peterson field	
	Fertilizer analyses (N-P_2O_5-K_2O)	Increase	Fertilizer analyses (N-P_2O_5-K_2O)	Increase	Fertilizer analyses (N-P_2O_5-K_2O)	Increase	Fertilizer analyses (N-P_2O_5-K_2O)	Increase	Fertilizer analyses (N-P_2O_5-K_2O)	Increase	Fertilizer analyses (N-P_2O_5-K_2O)	Increase	Fertilizer analyses (N-P_2O_5-K_2O)	Increase
		Lb.		*Lb.*		*Lb.*		*Lb.*		*Lb.*		*Lb.*		*Lb.*
1928					6-3-6	128	0-15-0	189						
1929	6-3-6	82	15-0-0	203	9-3-3	108	6- 9-0	313	3-9-3	142			3-9-3	201
1930	9-3-3	212			6-6-3	151	6- 9-0	430			3-9-3	139	6-3-6	228
1931	15-0-0	342	15-0-0	290	9-3-3	247	3- 9-3	363	6-6-3	276	6-9-0	238	3-9-3	374

TABLE 15.—*Increase in yield of seed cotton per acre from fertilizers on several soil types, showing progressive cumulative effect*—Continued

INCREASES IN YIELD EACH YEAR FROM SAME FERTILIZER ANALYSIS

Year	Houston black clay, King field 6–6–3 fertilizer	Houston black clay, Voelker field 15–0–0 fertilizer	Wilson clay, United States Cotton Breeding Station, 9–3–3 fertilizer	Wilson clay loam, Craig field 6–9–0 fertilizer	Bell clay, J. W. Jones field 6–6–3 fertilizer	Irving clay, O. Nelson field 6–9–0 fertilizer	Denton clay, Peterson field, 0–15–0 fertilizer
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1928			117	74			
1929	68	203	108	313	138		68
1930	143		146	430		109	122
1931	284	290	247	327	276	238	228

Because of this residual effect the current year's increase in yield in these experiments cannot be considered the full measure of benefit of a single fertilizer application. Rather the average results over a period of years would seem the best criterion. Furthermore, owing to this factor, some improvement in soil conditions of a more than transient nature may be anticipated. Differences in plant growth between fertilized and nonfertilized plots in the experiments were at times rather striking. There was a corresponding increase in the amount of plant residue returned to the soil of the fertilized plots. This would tend to build up the organic matter in the soil, increase the water-holding capacity, and decrease susceptibility to erosion—all of which are of paramount importance. While improvement of this kind is of too low magnitude to be measured during the duration of these experiments, it must, nevertheless, be considered among the advantages of fertilizer use.

GENERAL TREND OF RESULTS

Viewing these results collectively, for the region as a whole, the greatest response has been secured from the combined application of nitrogen and phosphoric acid. Nitrogen alone has usually shown a marked effect on early plant growth and color of foliage; but only in a few cases has such fertilizer given the greatest increase in yield. A few fields have shown response to phosphoric acid alone. For maximum effect on the majority of the soils, however, these two constituents must be present in combination. There has been relatively little response to potash alone, insofar as plant growth and yields are concerned; and in such respects this element is apparently of minor importance on the black-land soils. It has been repeatedly noted, however, that potash in the fertilizer ratio tends to promote seedling vigor. In the case of fields where the stand was reduced in the early stages of growth by seedling diseases or by a combination of unfavorable conditions the mortality of plants on plots treated with potash alone was frequently the lowest of any in the field.

Increases in yields were obtained in all of the experiments except those on the J. B. Earle field and at the United States San Antonio Field Station. With these reservations, increases ranging from 13 to 82 percent were obtained in 1929. In 1930 the increase on the least responsive field amounted to 17 percent and on the most responsive field to 117 percent; corresponding figures for 1931 are 21 and 106 percent, respectively.

SUPPLEMENTARY EXPERIMENTS

EXPERIMENTS WITH CONCENTRATED FERTILIZERS

Some of the newer concentrated fertilizer materials possess properties which should theoretically render them advantageous for use under Texas black-land conditions. Many of these fertilizers contain 2, or even 3, of the nutritive elements combined in a single salt. These elements are released to the soil solution and to the plant in the proportions in which they occur in the salt. This would appear to be an advantage in many of these soils, in which, as indicated by observation and laboratory investigations, fixation of added phosphoric acid seems to be a problem of considerable importance. The granular structure of a number of the commercial concentrated fertilizers, permitting slower solution than in the case of finely divided materials, offers an added advantage.

Accordingly, the fertilizer-ratio experiments, in which mixtures compounded of the more common commercial materials were used, have in many instances been supplemented by tests of the newer concentrated sources of nitrogen and phosphoric acid. Particular attention has been given the ammonium phosphates. These have been applied directly in their original concentrated form at rates equivalent in plant-food content to the lower analysis fertilizers, and with or without supplements to modify their plant-food ratios, or they have been used as the major sources of plant food in compounding lower analysis mixtures.

Table 16 presents some results from such fertilizers, prepared largely from the ammonium phosphates, in fields on which response to phosphoric acid has been appreciable. For ready comparison, results with the most favorable ratio compounded of ordinary commercial goods and with ratios of such fertilizers most nearly comparable in analysis to the concentrated mixtures are included.

TABLE 16.—*Increases in yield from fertilizers compounded from concentrated materials as compared with those from fertilizers compounded of ordinary commercial materials 1930–31*

1930

Soil type and experiment field	Ordinary commercial materials [1]						Concentrated materials [2]				
	Optimum ratio			Ratios most nearly comparable to concentrated ratios			Fertilizer		Major constituent of fertilizer	Increased yield of seed cotton per acre	Proportion of total crop at first picking
	Fertilizer analyses (N–P_2O_5–K_2O)	Increased yield of seed cotton per acre	Proportion of total crop at first picking	Fertilizer analyses (N–P_2O_5–K_2O)	Increased yield of seed cotton per acre	Proportion of total crop at first picking	Mixture no.	Analyses (N–P_2O_5–K_2O)			
		Pounds	*Percent*		*Pounds*	*Percent*				*Pounds*	*Percent*
Houston black clay, King	9–3–3	212	46	3–6–6	161	46	30	6–10– 4	Ammonium phosphate	129	50
				6–6–3	143	49	31	6–10– 4	Potassium ammonium phosphate	91	58
							NPK	15–30–15	Diammonium phosphate	−4	53
Houston black clay, noncalcareous phase, Range.	3–3–9	53	46	3–9–3	35	58	NPK	15–30–15	do	62	61
				3–3–9	53	46					
Houston black clay, Voelker	6–6–3	88	65	3–6–6	86	60	30	6–10– 4	Ammonium phosphate	144	56
				6–6–3	88	65	31	6–10– 4	Potassium ammonium phosphate	152	74
							NPK	15–30–15	Diammonium phosphate	94	72
Houston black clay, Blanks	6–6–3	132	48	3–6–6	130	49	NPK	15–30–15	do	79	45
Wilson clay, United States Cotton Breeding Station.	6–6–3	151	60	3–6–6	114	60	NPK	15–30–15	do	165	71

[1] Nitrogen from one-third each, sulphate of ammonia, nitrate of soda, and cottonseed meal; phosphoric acid from 18 percent superphosphate; potash from sulphate of potash. Fertilizers applied at rate of 600 pounds per acre.

[2] Mixtures compounded as follows; constituents given in order of importance:

Mixture no.	Components
5C	Ammonium phosphate (Ammo-Phos "A"), sulphate of potash, urea, cottonseed meal.
30	Ammonium phosphate (Ammo-Phos "A"), urea, sulphate of potash, cottonseed meal.
31	(1930) Potassium ammonium phosphate, ammonium sulphate, potassium nitrate, cottonseed meal. (1931) Diammonium phosphate, sulphate of ammonia, sulphate of potash.
33	Nitrophoska (15–30–15), sulphate of ammonia.
34	Diammonium phosphate, sulphate of ammonia.
41	Ammonium phosphate (Ammo-Phos "A"), sulphate of ammonia, sulphate of potash, cottonseed meal.
43	Diammonium phosphate, sulphate of ammonia, sulphate of potash, cottonseed meal.
45	Ammo-Phos-Ko, Ammo-Phos "B", cottonseed meal.
NPK	Nitrophoska, 15–30–15.

Except where noted, 6–10–4 ratios were applied at rate of 450 pounds per acre; 15–30–15 at rate of 150 pounds per acre.

TABLE 16.—*Increases in yield from fertilizers compounded from concentrated materials as compared with those from fertilizers compounded of ordinary commercial materials 1930–31*—Continued

Soil type and experiment field	Ordinary commercial materials						Concentrated materials				
	Optimum ratio			Ratios most nearly comparable to concentrated ratios			Fertilizer		Major constituent of fertilizer	Increased yield of seed cotton per acre	Proportion of total crop at first picking
	Fertilizer analyses ($N–P_2O_5–K_2O$)	Increased yields seed cotton per acre	Proportion of total crop at first picking	Fertilizer analyses ($N–P_2O_5–K_2O$)	Increased yield of seed cotton per acre	Proportion of total crop at first picking	Mixture no.	Analyses ($N–P_2O_5–K_2O$)			
		Pounds	*Percent*		*Pounds*	*Percent*				*Pounds*	*Percent*
1930											
Wilson clay loam, Craig	6–9–0	430	47	6–9–0	430	47	30	6–10– 4	Ammonium phosphate	232	40
				3–6–6	303	46	31	6–10– 4	Potassium ammonium phosphate	261	44
							NPK	15–30–15	Diammonium phosphate	268	65
Irving clay, O. Nelson	3–9–3	139	74	6–9–0	109	77	[3] 30	6–10– 4	Ammonium phosphate	210	83
				3–6–6	103	72	31	[3] 6–10– 4	Potassium ammonium phosphate	169	85
				3–9–3	139	74	NPK	[4] 15–30–15	Diammonium phosphate	186	87
							5C	[5] 3– 9– 3	Ammonium phosphate	126	71
1931											
Houston black clay, noncalcareous phase, Range.	9–3–3	340	41	3–9–3	278	52	33	[6] 16–24–12	Diammonium phosphate	393	37
				3–3–9	307	58	34	[7] 15–30– 0	do	181	38
							NPK	15–30–15	do	313	42
Houston black clay, Blanks	15–0–0	370	57	3–6–6	272	57	NPK	15–30–15	do	241	64
	6–6–3	316	58								
Bell clay, J.W. Jones	6–6–3	276	32	6–6–3	276	32	30	6–10– 4	Ammonium phosphate	217	30
				3–6–6	207	33	NPK	15–30–15	Diammonium phosphate	259	27
Wilson clay, United States Cotton Breeding Field Station.	9–3–3	247	38	3–6–6	89	43	NPK	15–30–15	do	207	38
Wilson clay loam, Craig	3–9–3	363	34	6–9–0	327	35	30	6–10– 4	Ammonium phosphate	223	32
				3–6–6	281	30	31	6–10– 4	Diammonium phosphate	249	27
							NPK	15–30–15	do	213	35
Irving clay, O. Nelson	6–9–0	238	63	6–9–0	238	63	30	6–10– 4	Ammonium phosphate	189	65
				3–6–6	103	72	31	6–10– 4	Diammonium phosphate	148	64
							41	6–10– 4	Ammonium phosphate	203	64
							43	6–10– 4	Diammonium phosphate	223	67
							45	6–10– 4	Ammonium phosphate	186	64
							NPK	15–30–15	Diammonium phosphate	126	67

[3] Applied at rate of 600 pounds per acre.
[4] Applied at rate of 200 pounds per acre.
[5] Applied at rate of 600 pounds per acre.
[6] Applied at rate of 186 pounds per acre; equivalent to application of a 20-30-15 fertilizer at a rate of 150 pounds an acre.
[7] Applied at rate of 150 pounds per acre.

The marked advantage of the concentrated fertilizers in accelerating maturity in 1930 is apparent. That year was characterized by a rather wet spring and a very dry summer. The advantage was not so great in 1931, in which season rainfall was better distributed. There is experimental evidence to indicate a greater mobility of concentrated fertilizers, and this may account, at least in part, for the difference in behavior with varying seasonal conditions. It has been observed in a number of the experiments that a marked advantage of fertilizers compounded from ammonium phosphates over those from ordinary materials, in favoring early plant growth and increasing the yields at first picking, has been materially reduced or has disappeared with advance of the season. The total yields in such cases were little or no higher, or even lower, than those resulting from use of ordinary materials.

The effect of concentrated fertilizers on early growth of cotton on Houston clay, Wilson clay loam, and Wilson clay is shown in figures 28 and 29, B.

In general, the increases in yield from the concentrated materials compare favorably with those from ordinary commercial goods. This is noteworthy in view of the fact that the analyses of the concentrated fertilizers differ materially in some cases from those of the commercial mixtures and particularly from those found most effective in the fertilizer-ratio trials. The results have not, however, been entirely consistent. Concentrated fertilizers with formulas better suited to the prevailing soil and crop needs seem to offer possibilities in this section.

One of the problems encountered in the use of these fertilizers in districts having lighter textured soils has been the risk of injury to germination and early growth. Little tendency in this direction has been encountered in these experiments, notwithstanding the fact that the materials have been applied at relatively high rates and in close proximity to the seed. Freedom from injury of this kind is probably due to the high absorptive capacity of the prevailing soils.

While the results so far obtained have not consistently demonstrated the advantages of concentrated fertilizer materials over those of lower analysis that might be anticipated on theoretical grounds, there is promise that selection of more appropriate ratios and materials, and more effective placement may permit fuller realization of such advantages. Experiments in this direction are in progress.

EXPERIMENTS WITH VARIOUS NITROGEN SOURCES

A number of comparative tests of various sources of nitrogen have been made. The nitrogen carriers were combined in 6–10–4 fertilizer and applied on several of the soil types covered by these experiments. The results do not indicate decided advantage for any of the older and more commonly used nitrogen carriers. Some of the newer, concentrated materials, which carry nitrogen alone or combined with other plant-food constituents, have given more favorable results on yields. This is particularly the case with the ammonium phosphates. However, it appears likely that the advantage is to be attributed in part to the combined source of nitrogen and phosphoric acid, rather than to the nitrogen source alone.

EXPERIMENTS WITH FERTILIZERS ON COTTON FOLLOWING CLEAN FALLOW

For a number of years the Division of Cotton, Rubber, and other Tropical Plants of the Bureau of Plant Industry has been conducting at its Greenville station a program of experiments on the relation of clean fallowing to cotton root-rot control. A material reduction in root-rot infestation after 2 years of such fallow treatment has been reported by McNamara (*31*) and McNamara and Hooton (*32*).

In connection with their experiments these investigators noted that cotton following clean fallow on the Wilson clay soil of the Greenville station generally made an abnormally rank vegetative growth as compared with that on land in continuous cotton, but that the yields were not increased in proportion. This behavior indicated an excess supply of moisture or available nitrogen, or both, and suggested the probable value of fertilizer supplements, especially those containing phosphoric acid. Another observation frequently made was that the initial growth of young cotton on land previously in clean fallow was appreciably retarded, although this condition disappeared later in the season.

As supplements to the fertilizer experiments on Wilson clay at the Greenville station described above, advantage was taken of the opportunity afforded for making applications of certain fertilizers to cotton immediately following different periods of clean fallow. Four such experiments have been conducted at Greenville, 1 in 1929 following 2 years' fallow, 1 in 1930 following 3 years' fallow, and 2 in 1931 following 3 and 4 years' fallow, respectively. With one exception, that of the experiment after 4 years' fallow in 1931, there have been pronounced responses to phosphatic fertilizers. The initial retardation of growth was overcome, marked acceleration of maturity resulted, and considerable increases in yield were obtained. Additional applications of nitrogen or potash were ineffective in producing any further increases. The results are presented in table 17 and the effects on early growth are illustrated in figure 30, *A* and *B*. The lack of response to phosphoric acid in the case of the one exception noted, that of cotton following 4 years' fallow, is difficult to explain in the light of present information.

TABLE 17.—*Results of fertilizer application to cotton following clean fallow on Wilson clay, United States Cotton Breeding Field Station, Greenville, Tex., 1929–31*

Plot treatment	1929, following 2-year fallow		1930, following 3-year fallow		1931, following 3-year fallow		1931, following 4-year fallow
	Yield of seed cotton per acre	Proportion of total yield at first picking	Yield of seed cotton per acre	Proportion of total yield at first picking	Yield of seed cotton per acre	Proportion of total yield at first picking	Yield of seed cotton per acre
	Pounds	*Percent*	*Pounds*	*Percent*	*Pounds*	*Percent*	*Pounds*
Superphosphate [1]	1,053	43	904	59	1,338	63	1,444
Check	876	29	675	46	816	34	1,510
Superphosphate+potash [2]	996	48	870	60	----------	----------	1,497
Superphosphate+nitrogen [3]	995	46	839	66	----------	----------	1,617
Dicalcium phosphate [4]	----------	----------	----------	----------	1,265	58	----------

[1] Superphosphate (18 percent P_2O_5) at 400 pounds per acre.
[2] Superphosphate (18 percent P_2O_5) at 400 pounds per acre; sulphate of potash at 40 pounds per acre.
[3] Superphosphate (18 percent P_2O_5) at 400 pounds per acre; nitrate of soda at 100 pounds per acre.
[4] Dicalcium phosphate (40 percent P_2O_5) at 180 pounds per acre.

FIGURE 30.—*A*, Effect of phosphatic fertilizer on very young cotton following 3-year fallow on Wilson clay, United States Cotton Breeding Field Station, Greenville, Tex.; rows at left treated with 40-percent dicalcium phosphate at 180 pounds per acre, rows at right unfertilized; photographed June 9, 1931. *B*, Effect of phosphatic fertilizer on growth of cotton following 3-year fallow on Wilson clay, United States Cotton Breeding Field Station; rows at left treated with 18-percent superphosphate at 400 pounds per acre, rows at right unfertilized; photographed July 10, 1931. *C*, Effect of nitrogen fertilizer on cotton following sorghum on Houston black clay, W. H. A. Nelson field, Travis County, Tex.; rows at left unfertilized, rows at right treated with 15–0–0 fertilizer at 600 pounds per acre; photographed July 16, 1930.

McNamara and Hooton (*32*) have discussed the value of clean fallow in root-rot control. The treatments reported here, which are a part of a series that they are studying, have all been consistent with the results of their work reported earlier. Root-rot infestation was reduced to a minimum in the cotton crop following the fallow, and in most instances this reduction has carried over in the second and third succeeding crops. As pointed out by these authors, however, clean fallows are expensive to maintain and their use can be recommended only in a limited way.

The results with fertilizer supplements indicate that, from an economic standpoint, the admittedly limited scope in which such methods might find practical application may be considerably broadened by the use of phosphatic fertilizers. The yield from the phosphate plot following 2 years' fallow in 1929 (1,053 pounds of seed cotton an acre) would represent a yield nearly equal to the average[12] for this section if divided among the 3 years that the plot was under treatment.

EXPERIMENTS WITH FERTILIZERS FOR COTTON FOLLOWING SORGHUM

Grain sorghums are important feed crops in the Texas black-land section, particularly in the southern portion. On many farms they are the principal source of hay and furnish a considerable proportion of the grain consumed. The crop is frequently introduced into a rotation with cotton on land badly infested with root rot as a means of checking further spread and partially controlling the disease. For this purpose it is probably the most effective crop available.

The depressing effect of sorghums on crops which follow in rotation is well recognized. Breazeale (*4*), in some early work, attributed this to toxic properties in roots and stubble which interfered with normal biological soil processes. Later Conrad (*7*) demonstrated that sorghum roots and stubble, because of high soluble carbohydrate content, encouraged activity and reproduction of micro-organisms to such a degree that they competed with succeeding crops for nitrates. He further demonstrated that nitrogen fertilizers offset the depressing effect to a large extent. His conclusions are substantiated by the work of Wilson and Wilson (*73*).

Such effects of sorghum on succeeding crops are frequently pronounced in this section. During progress of the experiments described herein supplementary tests of fertilizers for cotton following sorghum were made in a number of instances. Such applications were made on Houston black clay, Houston clay, Bell clay, and Denton clay. Without exception there was excellent response to nitrogen fertilizers. The results from two such experiments are given in table 18 as representative. Data from the Nelson experiment were obtained on the W. H. A. Nelson farm in Travis County on Houston black clay, gravelly phase. Broadcast sorghum had been grown for hay in 1929 and the experimental results were obtained with the cotton crop of 1930. The other experiment was conducted in 1931 on the Blanks plantation, Caldwell County, on Houston clay. The field had been cropped to hegari (in rows) in 1929 and 1930.

[12] The average yield of lint cotton in the black-land section for the years 1916 to 1922, inclusive, is reported as 151 pounds per acre. (Tex. Agr. Expt. Sta. Bul. 365, *48*, *p. 6*.)

TABLE 18.—*Effect of fertilizer on cotton following sorghum*

NELSON EXPERIMENT NO. 1, 1930

Fertilizer treatment [1]	Yield of seed cotton per acre	Increased yield of seed cotton per acre	Proportion of total yield at first picking
	Pounds	*Pounds*	*Percent*
Check	330		21
15–0–0	716	386	47
3–9–3	486	82	45
3–3–9	472	−5	35
Check	477		32
9–3–3	617	140	46
Yield, continuous cotton	609		

BLANKS EXPERIMENT NO. 1, 1931

Fertilizer treatment	Quantity per acre	Yield of seed cotton per acre	Increased yield of seed cotton per acre	Proportion of total yield at first picking
	Pounds	*Pounds*	*Pounds*	*Percent*
6–10–4 [2]	300	589	292	67
Check		297		66
Sulphate of ammonia	100	463	166	78
6–10–4 [2]	600	584	269	66
Check		315		67
Sulphate of ammonia	200	645	330	66

[1] 600 pounds fertilizer per acre.
[2] 90 percent of the nitrogen from sulphate of ammonia, 10 percent from cottonseed meal.

NOTE.—Plots occur in the field in the same order as they are presented above. In calculating increases from fertilizer, treated plots adjoining check plots are compared with those checks. Intermediate plots are compared with the average of 2 nearest checks.

In the Nelson experiment, while three of the treatments increased yields, ratios high in nitrogen were by far the most effective. Further, nitrogen alone (15–0–0) was more effective than an equivalent application of plant food in a 9–3–3 fertilizer. The yield recorded in table 18 as obtained in continuous cotton was secured in the same field with all cultural conditions identical except that no sorghum crop intervened. It is apparent that both the 9:3:3 and 15:0:0 ratios completely offset the harmful effect of the sorghum crop, and that nitrogen alone gave a further increase of approximately 100 pounds of seed cotton an acre. The effect of nitrogen on growth of cotton on Houston black clay previously cropped to sorghum is shown in figure 30, *C*.

The data of the Blanks experiment are arranged in order as the treatments supply increasing amounts of nitrogen. In general the response to fertilizer is in the same order and nitrogen was the element most effective in increasing yields under these conditions. The heaviest application of nitrogen was the most effective. Increases in yield of considerable magnitude were obtained from all treatments. While yields from comparable land cropped continuously to cotton are not available for comparison in this experiment, it is probable that even the least effective treatment fully counterbalanced the depressing effect of the sorghum crop.

These results suggest that sorghum, followed by a nitrogen fertilizer for the succeeding crop, might profitably find a wider use in rotations designed to effect partial control of the root-rot disease. Some further applications of such treatment are discussed under the heading Relation of Fertilizers to the Control of Cotton Root Rot (p. 57).

INDIRECT CONTROL OF COTTON ROOT ROT THROUGH USE OF FERTILIZERS

The experimental results presented above furnish repeated evidence of accelerated maturity and increased yields of cotton as a consequence of fertilizer application. In direct proportion as these two well-defined effects of fertilizers are exerted they will favor evasion or offsetting, respectively, of losses normally occasioned by root rot. The ultimate result may properly be termed "indirect control."

EVASION OF LOSSES THROUGH ACCELERATED MATURITY

Hastening of maturity has been very marked and is of particular significance. An example is furnished by the Craig experiment of 1930 on Wilson clay loam. On a plot treated with (concentrated) 15–30–15 fertilizer (at 150 pounds per acre), 65 percent of the total crop was secured at the first picking on August 19; while on the same date only 25 percent of the crop was secured from unfertilized plots. Obviously cotton plants dying of root rot after August 19 would not cause nearly so great a crop loss on fertilized land as on untreated areas, and even where cotton dies earlier than this the loss would be appreciably diminished. Similarly in 1931, on the W. E. Jones field on Houston black clay, 40 percent of the total crop was secured at first picking September 1 from a 6–3–6 plot, as compared with 27 percent from check plots. In 1929 in the J. W. Jones experiment (series 2) on Bell clay, a plot treated with 6–6–3 fertilizer yielded at the rate of 381 pounds of seed cotton per acre at the first picking on August 21. An adjoining unfertilized plot yielded at the rate of 129 pounds on the same date. These two plots are shown in figure 16, to which reference has already been made.

The experiments furnish many instances in which the early harvest from fertilized plots approached or even exceeded the total yield on unfertilized ground. In figure 31 are presented graphically the yields of fertilized plots at first picking, as compared with the total yields of check plots, for the Craig field in 1930 and the King field in 1931. The better fertilized plots yielded almost as much cotton at the first picking as did check plots for the entire season. Under conditions of severe root-rot infestation yields at early pickings frequently constitute the major part of the crop. The importance of early maturity is accordingly obvious, and fertilizers which favor it offer a means of evading, or insuring against, excessive losses. Likewise, the higher the proportion of the total crop that can be harvested at an early date, the lower will be the loss from insect damage or crop deterioration in the later season.

OFFSETTING LOSSES THROUGH INCREASED YIELDS

While no exact method of estimating losses from root rot in a given field is known, it seems that increases in yield of the magnitude secured in these experiments should counterbalance losses in most cases. The results on several of the fields offer concrete evidence on this point.

When the Cooper field was selected November 8, 1930, 96 percent of the cotton was dead. During 1931, when fertilizer applications were made, 84 percent of the cotton died. Accordingly the results were obtained under conditions of extreme root-rot infestation. Yet the most favorable fertilizer ratio increased the yield by 303

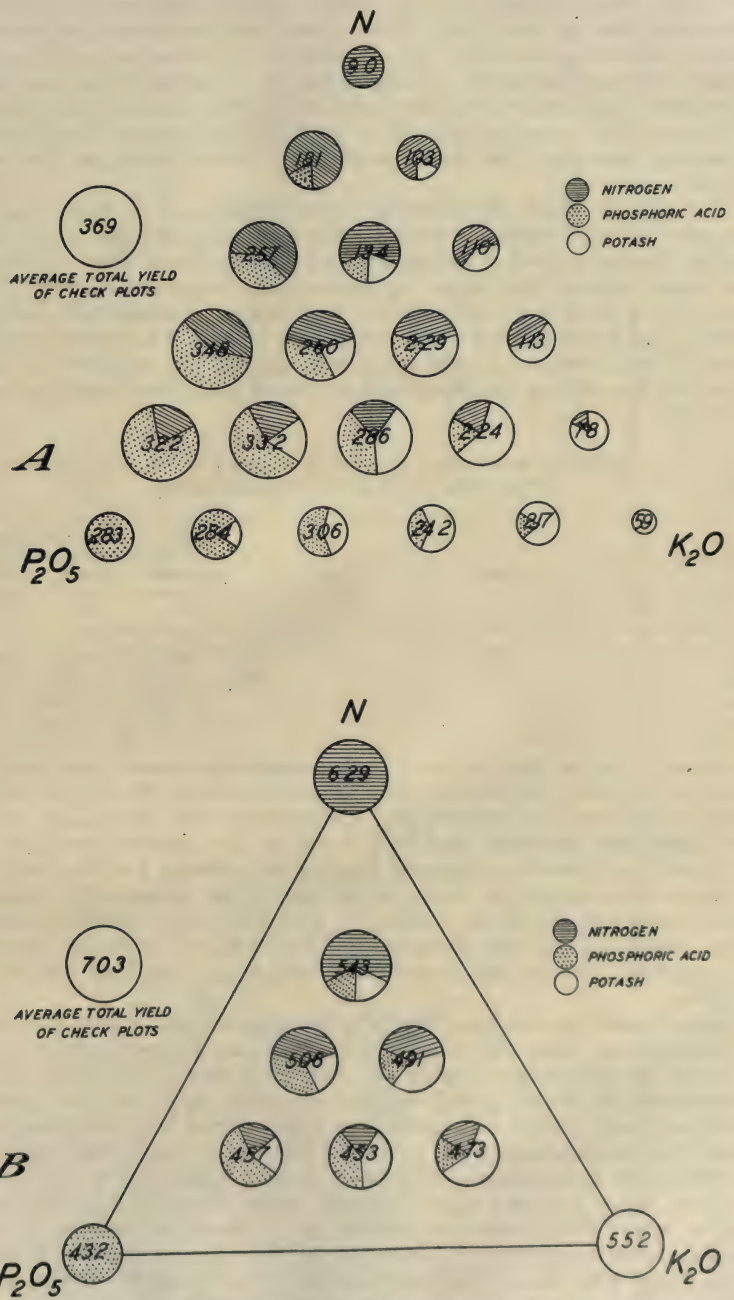

FIGURE 31.—Yields (pounds per acre) obtained at first picking from fertilized plots of cotton as compared with total yield of the check plot for the Craig experiment August 19, 1930 (*A*), and the King experiment September 23, 1931 (*B*). Areas of circles are proportional to yields of seed cotton per acre.

pounds of seed cotton an acre, which must be well in excess of any probable loss by root rot. Other fertilizers produced increases of almost equal magnitude. A considerable proportion of these increases can undoubtedly be attributed to acceleration of maturity. It is highly significant that the yield of the 9–3–3 plot at first picking on September 3 was 563 pounds of seed cotton an acre, which is only 8 pounds less than the average yield of check plots for the entire season.

The area in which the fertilizer-ratio experiment on the Craig field lies is all infested with the root-rot disease. Just a little to the south and in the same field is an area in which no cotton dies. This area has been utilized for some supplementary experiments, and yields data for a four-row check plot, practically noninfested with the disease, are available for 1929, 1930, and 1931. The location of this plot (*B*) with respect to the main experiment (*A*) is shown in figure 32 which also shows the distribution of root rot in the field September 13, 1928.

TABLE 19.—*Yields of seed cotton per acre of infested 6–9–0 plot compared with noninfested check plot, Craig experiment*

Year	Yield of check plot noninfested with root rot	Yield of 6–9–0 plot infested with root rot	Yield increases in excess of root-rot loss
	Pounds	*Pounds*	*Pounds*
1929	500	730	230
1930	406	739	333
1931	358	680	322

Table 19 gives the yields of this noninfested check plot for the 3 years of record. There are also shown yields of the 6–9–0 plot in which root rot was prevalent. Considering the proximity of the two plots and the fact that both were in the same experiment and subjected to the same cultural treatments except for the fertilizer, a direct comparison of their yields should be reasonably accurate. Such a comparison shows (table 19) that the 6–9–0 fertilizer entirely offset losses due to the disease, and in addition produced increases ranging from 230 pounds of seed cotton per acre in 1929 to 333 pounds in 1930.

Ezekiel and Taubenhaus (*14, p. 988*) suggest, as a result of 6 years' measurements, that the reduction in yield as a consequence of root rot may be estimated roughly as averaging about 50 percent of the percentage of plants killed by the disease prior to first picking. Some of these plants will produce a partial crop; on the other hand there will be some loss from cotton dying subsequent to first picking. A method of estimating losses, such as that suggested by the above authors, takes account of these losses which vary with the maturity of the crop. While such a method can at best be only an approximation, it is interesting to use it as a basis for computing losses of crops from root rot in the infested fields occupied by these experiments. The pertinent data are presented in table 20.

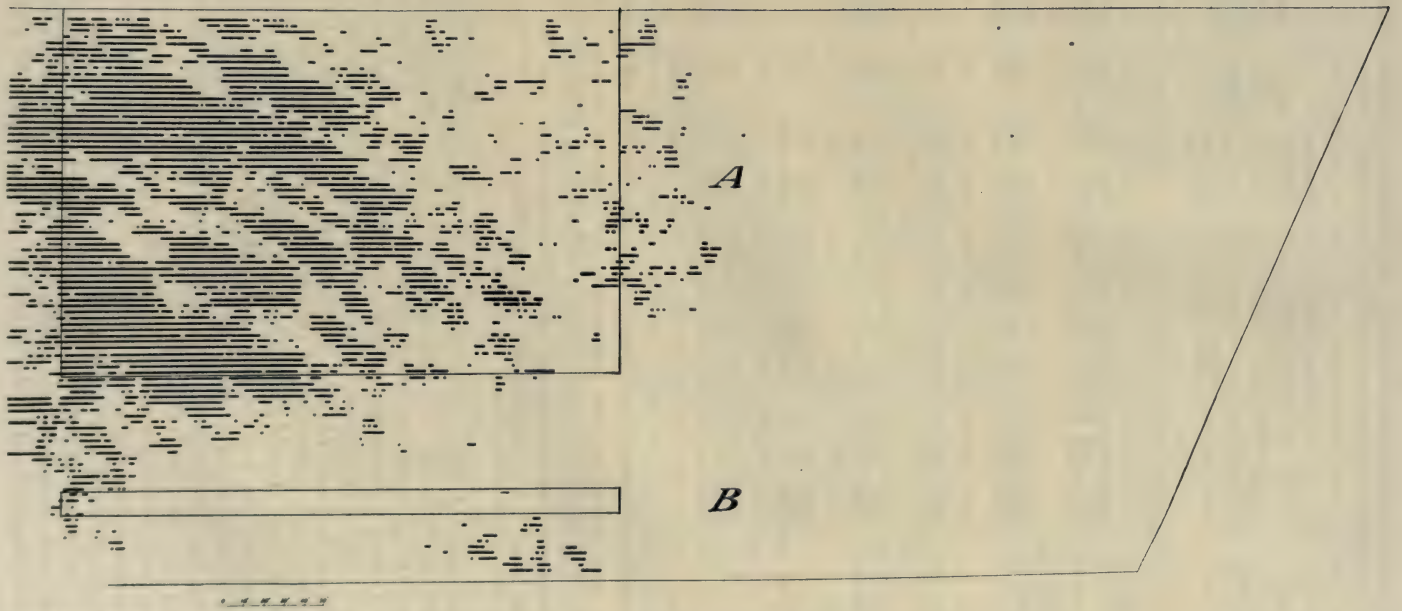

FIGURE 32.—Distribution of dead cotton in the Craig field September 13, 1928: *A*, Area of fertilizer-ratio experiment included in the calculation of percentage of dead cotton; *B*, check plot that was very slightly infested.

TABLE 20.—*Yields of seed cotton per acre of check plots corrected for root-rot losses compared with uncorrected yields from fertilized plots*

Soil type and field	Year	Date of first picking	Dead cotton on check plots at first picking		Reduction in yield due to root rot [1]	Yield of check plots (average)		Yield of fertilized plot	Fertilizer ratio (N–P_2O_5–K_2O)	Dead cotton on fertilized plot
			Date of record	Percent		Actual	Corrected [2]			
					Percent	*Lb.*	*Lb.*	*Lb.*		*Percent*
Houston black clay:										
King	1929	Aug. 28	Oct. 29	7.1	3.6	634	658	729	6–3–6	7.1
	1930	Aug. 21	Oct. 24	4.0	2.0	500	510	671	9–3–3	3.4
	1931	Sept. 23	Oct. 21	39.8	19.9	703	878	930	6–6–3	28.8
Substation no. 5, Texas Agricultural Experiment Station	1931	Sept. 22	Oct. 7	56.4	28.2	533	742	558	9–3–3	63.3
Voelker	1929	Aug. 19	Nov. 4	22.8	11.4	612	691	774	3–6–6	19.6
	1931	Aug. 18	Oct. 22	73.2	36.6	604	953	729	15–0–0	72.3
Houston clay:										
Cooper	1931	Sept. 3	Sept. 10	78.0	39.0	571	936	954	9–3–3	56.0
Bell clay:										
J. W. Jones [3]	1929	Aug. 21	Sept. 14	3.4	1.7	592	602	775	3–9–3	1.6
	1931	Sept. 2	Oct. 22	0.7	0.4	950	954	1,108	6–6–3	0.3
Wilson clay:										
United States Cotton Breeding Station	1928	Oct. 9	Nov. 8	24.9	12.5	503	575	613	6–3–6	25.3
	1929	Aug. 26	Sept. 18	0.6	0.3	572	574	678	9–3–3	1.2
	1930	Aug. 26	July 17 [4]	0.7	0.4	533	535	687	6–6–3	0.3
	1931	Sept. 11	Sept. 9	10.7	5.4	933	986	1,086	6–3–6	10.4
Wilson clay loam:										
R. W. Craig	1928	Sept. 12	Sept. 13	45.0	22.5	279	360	376	3–9–3	50.0
	1929	Aug. 27	Sept. 19	29.2	14.6	454	532	688	6–6–3	28.6
	1930	Aug. 19	Oct. 27	8.3	4.2	369	385	739	6–9–0	4.0
	1931	Aug. 25	Sept. 8	34.5	17.3	343	415	675	6–6–3	32.1
Denton clay:										
Peterson	1929	Aug. 29	Nov. 5	17.0	8.5	244	267	442	3–9–3	13.9
	1930	Aug. 19	Oct. 30	6.5	3.3	473	489	628	6–3–6	6.7
	1931	Aug. 23	Oct. 19	21.5	10.8	508	570	688	6–6–3	22.1
Average				24.2			631	726		22.4

[1] One-half of the percentage of dead cotton at first picking is taken as the percentage reduction in yield due to root rot.

[2] The corrected yields represent the actual yields corrected by the estimated amount of root-rot loss shown. For example: With a loss of crop estimated at 20 percent, an actual yield of 400 pounds of seed cotton per acre represents 80 percent of the total yield that would have been obtained in the absence of such loss; and the corrected yield accordingly amounts to $\frac{400}{80} \times 100 = 500$ pounds.

[3] Records are from series 1 only of this experiment. Series 2 is noninfected.

[4] Later records from this field lost in a fire.

The percentages of dead cotton in table 20 were computed from map records made periodically for each of the fields. The dates of these maps do not in all instances coincide with the dates of first picking, but where this is not the case later records were used. The percentage reduction in yield due to root rot was calculated from the percentage of dead cotton on check plots. The average yield of check plots was then corrected by the amount of this factor. The corrected average yield of check plots should therefore be a close approximation to the potential yield of the field if root rot had not been present, within, of course, the limits of accuracy of the method. For comparison there are presented the yields of plots in each experiment which have been treated with a favorable fertilizer.

There are only two instances in which the yield of the fertilized plot is not in excess of the corrected average yield of check plots, or the potential yield of the field without root rot. In the remaining 18 cases in table 20 fertilizers not only completely offset the calculated loss from root rot but increased the yields by a further considerable margin. As an average for all fields fertilizers counterbalanced losses and

produced an added increase in yield amounting to 95 pounds of seed cotton an acre. The percentage of root rot on fertilized and check plots compared is very nearly the same as an average and very nearly the same in most of the individual comparisons. In this connection it was necessary to eliminate from table 20 certain plots of certain experiments treated with optimum fertilizer because of a somewhat lower percentage of root rot than occurred in check plots, due probably to direct control of the disease which is discussed in a subsequent paragraph.

The data are rather conclusive in demonstrating the value of fertilizer usage as a means of indirectly controlling the root-rot disease. By accelerating maturity, losses which the disease might cause tend to be evaded and by increasing yields they have in these experiments been more than offset.

RELATION OF FERTILIZERS TO THE CONTROL OF COTTON ROOT ROT

The effects of fertilizers favoring evasion and compensation of losses from cotton root rot as a consequence of accelerated maturity and increased yields of crop are essentially indirect in nature. Another and more direct effect of such treatments in actually reducing the rate of plant mortality resulting from the disease has been indicated in the course of the experiments.

While the evidence of such an effect in a number of instances is definite the fundamental factors involved have not as yet been fully determined. Whether the increased vigor of the plant increases its resistance is as yet an open question. Much of the evidence seems to support this view. Regardless of the cause, however, the more effective fertilizers in many of these experiments have actually decreased the proportion of plants which have succumbed to the disease.

In a field thoroughly infested with root rot significant reduction in its severity has not been noted following a single fertilizer application, but only as a result of the cumulative action of repeated applications. However, in a number of instances, where the apparent infestation was first reduced by growing nonsusceptible rotation crops, or by a combination of rotation and subsoiling significant further reduction has followed single fertilizer treatments.

A striking example of such behavior was encountered in 1930 in a supplementary fertilizer experiment with cotton on the W. H. A. Nelson field (no. 1), Houston black clay, gravelly phase. Here the level of root-rot infestation had been greatly lowered by combination of a sorghum crop and subsoiling in 1929. The percentages of dead cotton, calculated from map records of the several plots during the 1930 season, are shown in table 21, together with similar figures secured on the same area in the cotton of 1928, before any treatment. A graphic representation of the data for the subsoiled area is given in figure 33 *A*.

TABLE 21.—*Effect of fertilizers on root rot and yield of cotton W. H. A. Nelson experiment no. 1, 1930*

Plot no.[1]	Fertilizer analyses (N–P_2O_5–K_2O)	Percentages of dead cotton		Increased or decreased yield of seed cotton per acre due to fertilizer
		Oct. 4, 1928, before treatment	Oct. 31, 1930, following sorghum grown in 1929	
				Pounds
SUBSOILED				
K–21	15–0–0	54.5	0.1	211
K–check		43.4	3.1	
K–5	3–9–3	41.9	1.2	124
K–12	3–3–9	49.8	1.5	145
K–14	9–3–3	56.4	.6	102
K–check		50.4	2.5	
NONSUBSOILED				
Check		83.5	38.9	
21	15–0–0	73.0	22.2	386
5	3–9–3	59.1	29.7	82
12	3–3–9	68.4	22.6	−5
Check		88.4	30.1	
14	9–3–3	90.9	18.6	140

[1] Plots are given in same order as they occurred in the field.

Whereas the distribution of dead cotton was relatively uniform in 1928, with if anything a lower proportion on plots later made check plots, the situation was very different in 1930. In the latter year there was a marked suppression of root-rot loss on the plots treated with high-nitrogen fertilizers. This is true in both subsoiled and nonsubsoiled areas, although the level of infestation was appreciably higher on the latter. Correspondingly it was the high-nitrogen ratios which were most effective in increasing yields.

Data of another experiment on the same farm are presented in table 22. This area was in cotton in 1929 and root rot was severe and uniformly distributed. It was planted to sorghum in 1930, was subsoiled in the summer of that year, and was returned to cotton in 1931 with fertilizer treatments as noted. The percentage of dead cotton on each plot on September 25 is shown in the table, together with the effect of fertilizers on yields.

TABLE 22.—*Effect of fertilizers on root rot and yields, W. H. A. Nelson experiment no. 2, Sept. 25, 1931*

Plot no.	Fertilizer used and quantity per acre	Dead cotton	Increased yield of seed cotton per acre due to fertilizer
		Percent	*Pounds*
K–N–100	Sulphate of ammonia, 100 pounds	4.2	69
K–check	Check	5.4	
K–50–300	6–10–4[1], 300 pounds	1.7	185
K–50–450	6–10–4[1], 450 pounds	0.0	119
K–N–200	Sulphate of ammonia, 200 pounds	0.3	74
K–check	Check	4.4	

[1] 90 percent of the nitrogen from sulphate of ammonia, 10 percent from cottonseed meal.

All treatments were effective in increasing yields. While the differences in degree of infestation are not large, there is a consistently lower proportion of dead plants on the fertilizer plots.

A parallel example was noted in an experiment in 1931 on Denton clay on the Carl Stried farm.[13] This area, which had produced oats in

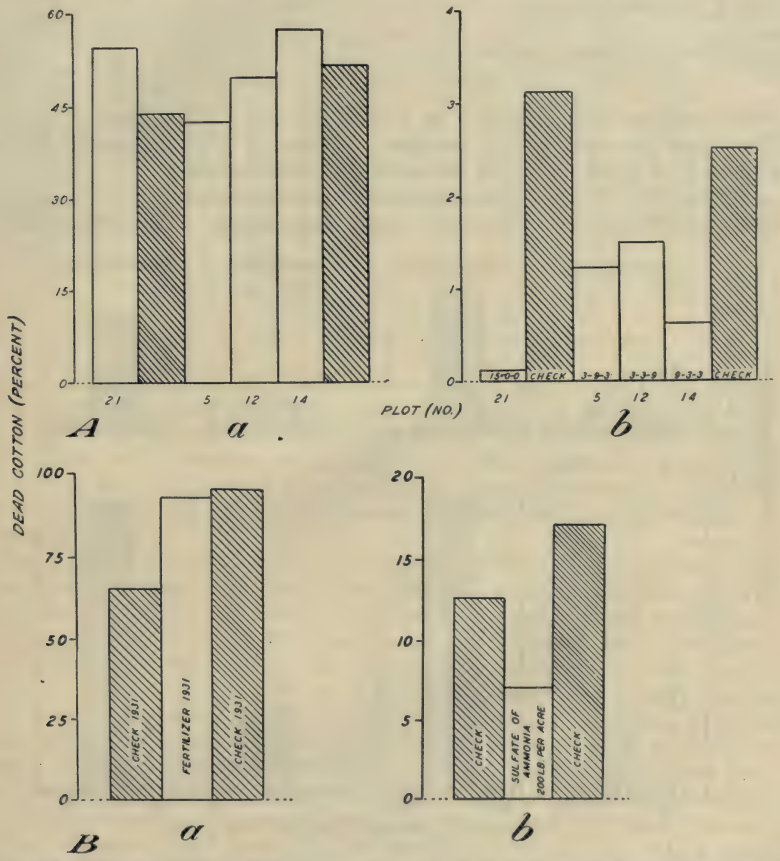

FIGURE 33.—Effect of fertilizer on the prevalence of root rot. *A*, W. H. A. Nelson experiment no. 1: *a*, Percentage of dead cotton October 4, 1928, before treatment; *b*, percentage of dead cotton October 31, 1930, following sorghum and subsoiling in 1929 and fertilizers in 1930. *B*, Carl Stried field: *a*, Percentage of dead cotton in the fall of 1927 before treatment; *b*, percentage of dead cotton October 23, 1931, following oats in 1928–29, sorghum in 1930, and fertilizers in 1931.

1928 and 1929 and sorghum in 1930, had relatively little root rot when returned to cotton in 1931. It was divided into 3 plots; 2 served as checks, and 1 was treated with sulphate of ammonia. The data of the experiment are shown in table 23 and depicted graphically in figure 33, *B*.

[13] This test was conducted as part of an experiment comparing the effects of noncotton crop and clean fallowing carried out by H. C. McNamara of the Office of Cotton, Rubber, and Other Tropical Plants. Through his cooperation the plot was made available for supplementary fertilizer experiments.

TABLE 23.—*Effect of fertilizer on root rot and yield of cotton, Carl Stried field, 1931*

Fertilizer treatment	Dead cotton		Increased yield of seed cotton per acre due to fertilizer
	Fall, 1927	Oct. 23, 1931	
	Percent	*Percent*	*Pounds*
Check	65.0	12.6	
Sulphate of ammonia, 200 pounds per acre	92.8	7.0	117
Check	95.4	17.2	

The fertilizer was effective in increasing the seed cotton yield by 117 pounds an acre and it resulted further in a significantly lower proportion of dead plants in the area of the treatment.

A similar effect was demonstrated in an experiment (no. 1) at the Blanks plantation on Houston clay, flat phase. The experiment

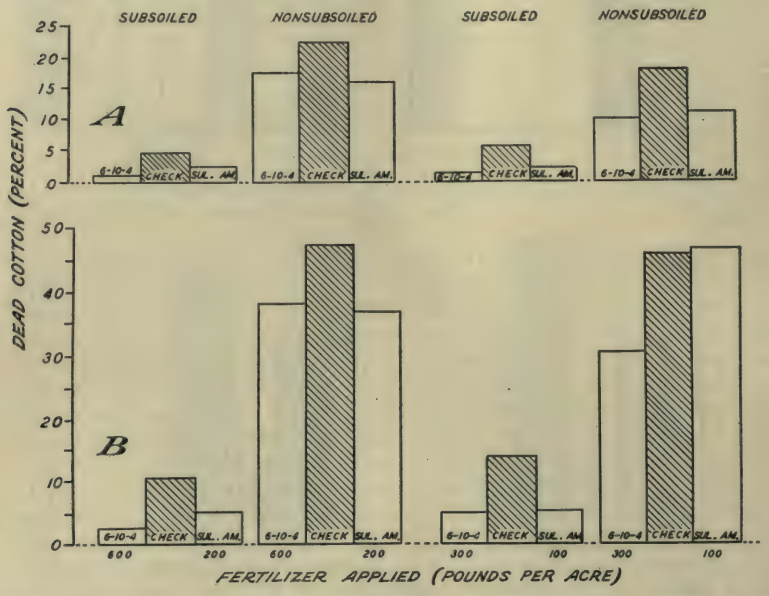

FIGURE 34.—Effect of fertilizers on the prevalence of root rot, Blanks experiment no. 1; percentage of dead cotton (*A*) July 21, 1931, (*B*) August 5, 1931.

field, heavily infested with root rot, was in cotton in 1928; it was cropped to hegari in 1929 and 1930, and half of the area was subsoiled in the summer of the latter year. This treatment greatly lowered the degree of infestation over the field, especially in the subsoiled area, when returned to cotton in 1931. An experiment with a number of fertilizers was conducted that year, the treatments being duplicated on the subsoiled and nonsubsoiled areas.

The fertilizer treatments and their effect on yields and on the distribution of dead cotton are shown in table 24. These data for July 21 are represented graphically in figure 34, *A*. The lower proportion of dead cotton on fertilized plots, as compared with adjoining check plots, is outstanding. All fertilizer treatments were very effective in increasing yields. In general, the effect of fertilizers on the proportion of dead plants was inversely proportional to their effect on yields.

TABLE 24.—*Effect of fertilizers on root rot and yield of cotton, Blanks experiment no. 1, 1931*

Plot no. and treatment	Fertilizer used and quantity per acre	Dead cotton, 1931		Increased yield of seed cotton per acre due to fertilizer
		July 21	Aug. 5	
Subsoiled:		*Percent*	*Percent*	*Pounds*
K–50–600	6–10–4 [1], 600 pounds	1.0	2.3	345
K–check	Check	4.6	10.1	
K–N–200	Sulphate of ammonia, 200 pounds	2.5	4.8	324
Nonsubsoiled:				
50–600	6–10–4 [1], 600 pounds	17.7	38.2	269
Check	Check	22.2	47.8	
N–200	Sulphate of ammonia, 200 pounds	16.0	36.8	330
Subsoiled:				
K–50–300	6–10–4 [1], 300 pounds	1.2	5.0	316
K–check	Check	5.3	13.5	
K–N–100	Sulphate of ammonia, 100 pounds	1.8	5.0	219
Nonsubsoiled:				
K–50–300	6–10–4 [1], 300 pounds	9.7	30.7	292
K–check	Check	18.0	46.3	
K–N–100	Sulphate of ammonia, 100 pounds	11.4	46.5	166

[1] 90 percent of the nitrogen from sulphate of ammonia; 10 percent from cottonseed meal.

This direct effect of fertilizers seems to be largely one of retarding the rate of spread of the disease and delaying the killing of plants. By August 5, on nonsubsoiled ground, the effect was less marked. The difference persisted on subsoiled ground, however, where the severity of the disease had been reduced to a greater extent. This is shown in figure 34, *B* which represents graphically the records of August 5.

The examples described above represent instances in which, the severity of root rot having first been reduced by growing nonsusceptible sorghum crops or by a combination of this practice and subsoiling, the disease was still further suppressed by suitable fertilizer treatment. The fertilizer most effective under these conditions was in all cases one relatively high in nitrogen content. In fertilizer-ratio trials a similar suppression of the disease has become evident in some fields where applications have been cumulative over a number of years. In general it is most marked on those fields which have been most responsive, and the most effective fertilizer has been that which increased production to the greatest extent. The Craig field presents the best example, and here the greatest reduction in root rot resulted from ratios combining phosphoric acid and nitrogen.

In 1927 before work was begun on this field, root rot was uniformly distributed over the area used for the ratio-experiment plots. It caused the death of 94 percent of the cotton in the west section of these plots that year. Figure 35 shows the distribution of dead cotton on the field, the areas included in the plots, and the area used in making the following calculations.

Identical fertilizers were applied to the same plots in each of the following years. Only a very slight indication of direct effect was noted in 1928, after 1 year's treatment. Evidence of an actual reduction in the proportion of plants killed by the disease became more pronounced with each succeeding year. In table 25 are given the percentages of cotton killed by root rot by the end of the 1931 season on the fertilized and check plots. The last column presents the ratios

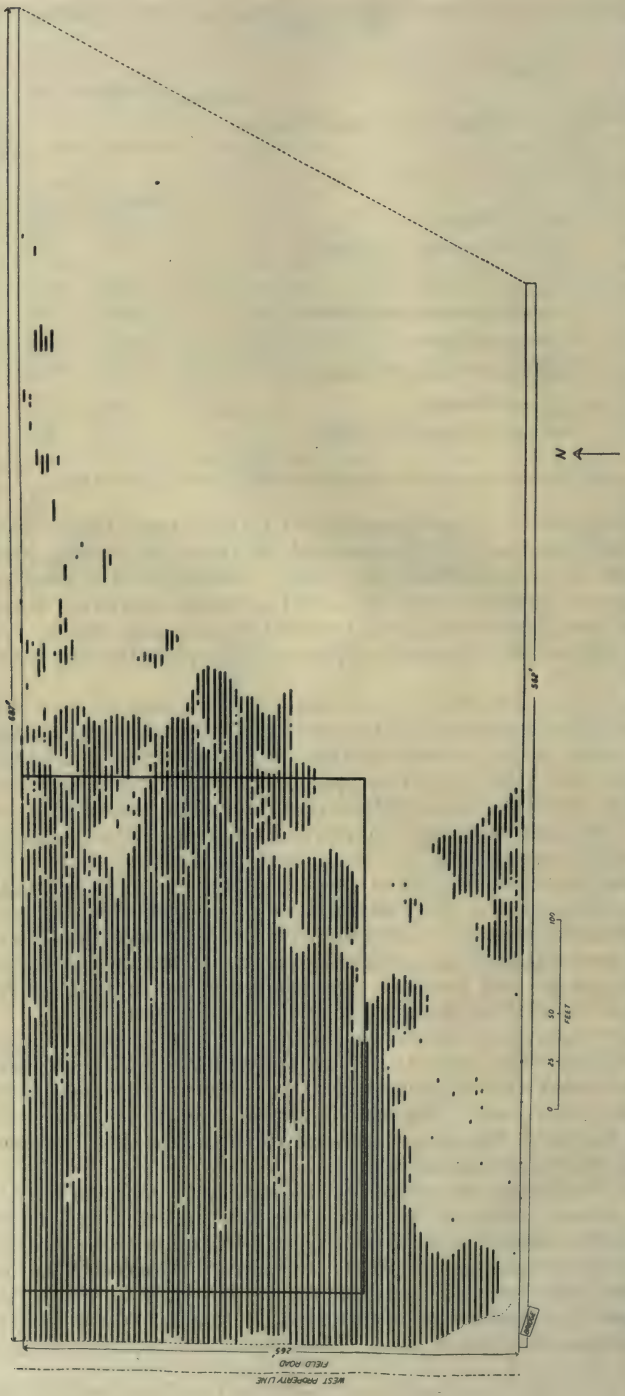

FIGURE 35.—Diagram of Craig field at the end of the 1927 season, black lines showing distribution of dead cotton before experimental treatments began, and the area included in the calculations for 1931.

between the proportion of dead cotton on the fertilized plots and that on the check plots, expressed as percentages. A value less than 100 indicates that less cotton was killed on the fertilized plot than on the comparable check, while a value greater than 100 indicates a reverse relationship. The comparisons appear more strikingly when plotted on the triangle graph (fig. 36).

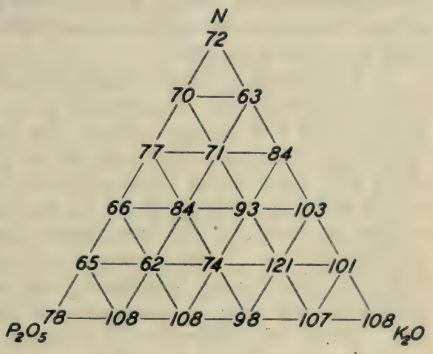

FIGURE 36.—Effect of fertilizers on root rot in the R. W. Craig experiment, showing ratio of percentage of dead cotton on fertilized plots to that on comparable check plots (X 100), October 26, 1931.

Both nitrogen alone (plot 21) and phosphate alone (plot 1) reduced the percentage of dead cotton. The greatest reductions, however, occurred from ratios combining these two constituents. Maximum reduction occurred on plot 5, which was treated with a 3–9–3 fertilizer. This same ratio gave the greatest increase in yield in 1931, and is very nearly of the same composition as the optimum ratio for 1929 and 1930, which was the 6–9–0. High potash ratios have apparently increased somewhat the proportion of plants killed, although the differences are probably so small that they lack significance. These figures in all cases were computed from map records made at the end of the season on October 26.

TABLE 25.—*Percentage of cotton killed by root rot on fertilized and unfertilized plots of Craig experiment, 1931*

Plot no.	Fertilizer analyses (N–P_2O_5–K_2O)	Dead cotton Oct. 26, 1931	Ratio, $\frac{\text{Percent dead on fertilizer plot}}{\text{Percent dead on comparable check plot}} \times 100$[1]
		Percent	
Check		25.5	
1	0–15– 0	19.8	78
2	0–12– 3	29.5	108
3	3–12– 0	19.0	65
Check		29.1	
4	0– 9– 6	31.3	108
5	3– 9– 3	23.6	62
6	6– 9– 0	30.8	66
Check		46.9	
7	0– 6– 9	45.8	98
8	3– 6– 6	41.0	74
9	6– 6– 3	54.0	84
Check		64.1	
10	9– 6– 0	49.3	77
11	0– 3–12	68.7	107
12	3– 3– 9	78.0	121
Check		64.3	
13	6– 3– 6	59.7	93
14	9– 3– 3	53.5	71
15	12– 3– 0	60.8	70
Check		87.4	
16	0– 0–15	94.7	108
17	3– 0–12	83.2	101
18	6– 0– 9	81.1	105
Check		77.1	
19	9– 0– 6	64.5	84
20	12– 0– 3	40.8	63
21	15– 0– 0	38.3	72
Check		53.3	

[1] Fertilizer plots adjoining check plots were compared with those plots; other fertilized plots compared with average of 2 nearest check plots.

Evidence of a similar reduction in dead cotton from fertilizer treatments is found in others of these fertilizer-ratio experiments, although it is in no case so conclusive as on the Craig field. In general, the greatest reduction in root rot has resulted from fertilizer ratios near the optimum for cotton production, and the effect is most pronounced where fertilizers have been most effective in stimulating plant growth and increasing yields.

It is clearly evident that the increase in yield secured in these experiments is not the result of a lowered infestation on fertilized plots when the magnitude of the two effects is considered. For example, on the subsoiled area of the Nelson experiment no. 1, a difference of 3 percent in dead cotton between plots K-check and K–21 could not have resulted in an increased yield of 211 pounds of seed cotton an acre for the treatment (table 21). Similarly in the Blanks experiment no. 1 the greatest contrast in percentage of dead cotton between check and fertilized plots is found when plot 50–300 of the nonsubsoiled area is compared with the check plot adjoining (table 24). Here the difference is 15.6 percent. An increase in yield of 292 pounds of seed cotton per acre could not be attributed to such a small reduction in root rot. In the Craig experiment 23.6 percent of the cotton died on plot 5. On the check plots with which this plot is compared mortality amounted to 38 percent. The difference of 14.4 percent could not account for an increased yield of 363 pounds of seed cotton per acre. Rather the two effects must be interpreted as being more or less independent, except as to cause, although the lowered infestation has necessarily contributed in small degree to the increased yields from fertilizer.

This effect of fertilizers on cotton root-rot disease is not of sufficient magnitude to indicate economic importance at present. It is highly significant, however, as reflecting the influence of soil fertility factors in general and of the relation of fertilizers to the root-rot disease. It also implies that the continued use of effective fertilizers in successive years, together with the application of other measures designed to restore or maintain fertility, may eventually lead to material control.

CONSIDERATIONS INVOLVED IN FERTILIZER USAGE

In the experiments reported herein response to fertilizers of suitable ratio has, with minor exceptions, been obtained on the more important soils of the Texas black-land prairie section. The magnitude of such responses varies materially with the soil type and the location and past history of fields on the same soil type. The extent to which fertilizer usage may find application to increasing efficiency of production and to reducing, directly or indirectly, losses from cotton root rot will be determined by the magnitude of the response that can be attained and by a number of factors of economic nature.

The prevailing soil and climatic conditions of the section present certain problems with regard to fertilizer usage which are widely different from those common to the older fertilizer-using territory. The more restricted rainfall places a limit on the maximum crop expectation, considerably below that prevailing in the more humid areas of the South. The soils, having developed under conditions of more limited rainfall, are in general more productive and less responsive to added plant food. The latter characteristic is further accentu-

ated by the heavy clay texture of the prevailing soils. These factors have combined to present certain problems more or less peculiar to the section, and optimum fertilizer practice will probably differ in some respects from that common elsewhere.

FACTORS AFFECTING FERTILIZER RESPONSE

The distribution of rainfall throughout the growing season undoubtedly affects the degree of fertilizer response in the black-land prairie section. Normally, rainfall is adequate to insure maximum fertilizer effect in the early part of the growing season. From about the middle of June until the middle of September, however, rains are infrequent and occur mostly as light showers. The surface 3 to 5 inches of soil gradually lose moisture until practically air-dry. Fertilizers placed in this zone accordingly become increasingly less effective. This has been reflected in the development of the cotton in these experiments. The fertilized plots showed marked superiority over check plots in May and early June and gradually lost some of their advantage as the season advanced.

The method of placement in the several experiments, particularly in the earlier years, was determined to a considerable extent by expediency, the depth depending upon whether placement was made in water furrows or opened beds, and upon the physical condition of the soil at the time of fertilizer distribution. Opportunity was therefore afforded for observation on the influence of fertilizer placement upon the degree of response. These observations have shown that nitrogen with relatively shallow placement may be fully effective in any season so far encountered in this section. This has been reflected in increased vegetative growth and deeper green color of plants with deep placement and shallow placement alike.

Phosphoric acid with shallow placement may be effective in a wet season, but is likely to fail of producing maximum returns in a dry season. On the other hand deep placement has been fully as effective as shallow placement in wet years. Accordingly, a depth of placement approximately 4 or 5 inches beneath the soil surface seems best suited under all conditions. A positive correlation between degree of response and depth of fertilizer placement can be shown in these experiments. Deep placement, therefore, offers opportunity for extending the period of maximum fertilizer effect well beyond the period of spring rains.

As pointed out in a previous section (p. 47), a number of fertilizer materials, in particular the ammonium phosphates, possess properties which should make them especially suitable for use under Texas black-land prairie conditions. The experiments have demonstrated their advantage in many instances over ordinary commercial materials in respect to enhanced early plant growth and accelerated maturity, and it is noteworthy that such advantage was most pronounced in the driest season encountered, 1930. This is highly significant, and suggests that a better understanding of these materials may lead to enhanced returns. Work along these lines is being continued.

The effectiveness of certain concentrated fertilizers in these experiments suggested that part of their value might be due to their granular structure or large particle size. The larger particles might be expected to dissolve and become available more slowly. Accordingly

experiments were conducted to compare coarse (3.5- to 5.5-mm diameter), medium (2.5- to 3.5-mm diameter), and fine (less than 1-mm diameter), superphosphate particles combined in 6–10–4 fertilizers and applied to a number of soil types. The results are not conclusive, but indicate some advantage for the larger particle sizes. Coarse superphosphate (18-percent P_2O_5) particles which had been applied in the field before cotton was planted were dug up and analyzed on August 22. It is significant that these particles contained at that time 9.14 percent of total phosphoric acid, of which 1.03 was water soluble and 8.92 percent citrate soluble.[14] Because of relatively deep placement they were in moist soil at the time and accordingly had been a potential source of readily available phosphoric acid for the growing cotton throughout the season.

The distribution of rainfall in this section makes the use of side dressings or split fertilizer applications uncertain. Fertilizers higher in nitrogen with respect to phosphoric acid than those in common use were found most effective on Houston black clay, Houston clay, and Wilson clay. In regions of better distributed rainfall these proportions of nitrogen and phosphoric acid would probably be supplied by applying mixed or complete fertilizer before planting and following this with a side application of nitrogen. Here, with rainfall uncertain after time of chopping cotton, this practice cannot be followed with any reasonable assurance of success. Accordingly, if a continuation of these experiments substantiates present findings, the need for such ratios will be indicated.

METHOD OF FERTILIZER APPLICATION

Common practice in this section is to bed or list the land for cotton in fall and winter. At planting time these beds are levelled off with a sweep on the planter which deposits the seed below the surface of the resultant, almost level field. Bedding is practiced as a means of insuring moist soil in which to plant, and for the additional object of securing drainage while the cotton is in the seedling stage.

Fertilizers for the experiments already described have been distributed from a week to 10 days in advance of planting. One of two methods has been followed. Either the fertilizer was deposited in the water furrows between the beds and the land subsequently rebedded; or beds were opened with a middle breaker or sweep, fertilizer distributed, and the beds then thrown back in their original position. A type of distributor was used which deposited the fertilizer in a rather concentrated stream and about an inch beneath the bottom of the furrow. Figure 5 shows fertilizer being distributed in this manner.

Such a method of application involves considerable risk. Drying winds are the rule at the time when placement must be made; and the soil may lose enough moisture to necessitate a delay in planting until rains supply the deficit, which may be beyond the optimum date. It further entails considerable labor.

Accordingly some experiments were initiated in which fertilizers were distributed at planting time with attachments on the cotton planter. Standard equipment was used with some simple modifications. Figure 37 shows cotton being planted on an experiment

[14] Analysis by E. R. Collins, assistant soil technologist.

with a standard two-row planter, while fertilizer is being distributed simultaneously with specially modified attachments. These experiments have demonstrated the entire feasibility of such practice, although, with the experience gained, some further modifications in the design of the fertilizer-distributing machinery suggest themselves. Such equipment will, when perfected, reduce to a minimum the overhead cost of fertilizer use.

ECONOMIC CONSIDERATIONS

Fertilizer usage is not an established practice in this section, and much of the work has necessarily been of an experimental nature. The rates of application have in most cases been arbitrary and rather liberal in magnitude. The sources of plant food have not

FIGURE 37.—Method of applying fertilizer simultaneously with planting by the use of attachments on a two-row cotton planter.

necessarily been the most economical, and fertilizers have not been applied on areas larger than the plots ordinarily used in such experiments. In their inception the plans of the experiments did not necessarily contemplate their study from an economic point of view; nevertheless data have accumulated on which such a study might be based.

The price of cotton will determine to a large extent the profits to be anticipated from the use of fertilizer, and this will of course vary from year to year. The cost of fertilizer will vary, but within more narrow limits. Current valuations for a number of the more common fertilizer analyses are given in table 27, computed on the assumption that the sources of nitrogen, phosphoric acid, and potash are, respectively, sulphate of ammonia alone, 20 percent superphosphate, and muriate of potash. From the experimental results and these data the reader may make his own calculations, and these can be adjusted to meet local and seasonal conditions.

TABLE 27.—*Approximate average retail cost*[1] *of experimental fertilizers used in 1930–31*

Fertilizer analyses		Cost per ton	Cost per 600-pound application	Fertilizer analyses		Cost per ton	Cost per 600-pound application
No.	N–P_2O_5–K_2O			No.	N–P_2O_5–K_2O		
1	0–15–0	$18.18	$5.45	13	6–3– 6	$25.86	$7.76
5	3– 9–3	22.03	6.61	14	9–3– 3	30.67	9.20
8	3– 6–6	21.54	6.46	16	0–0–15	15.78	4.73
9	6– 6–3	26.34	7.90	21	15–0– 0	39.78	11.93
12	3– 3–9	21.07	6.32				

[1] Costs calculated from data reported by Fraps and Asbury (*17, p. 11*): Cost of nitrogen as in sulphate of ammonia, 13.26 cents per pound; phosphoric acid as in 20 percent superphosphate, 6.06 cents per pound; potash as in muriate of potash, 5.26 cents per pound.

If the average price received by producers on December 15, over the period from 1920 to 1930, inclusive, is taken as the value of the cotton, and the cost of fertilizers is computed as above outlined, the increased yields produced by the more effective fertilizer in the trials on the most prevalent soils will pay the cost at least. By such calculations most of the experiments show a narrow to very satisfactory margin of profit. As regards soil type, fertilizer application is shown to be highly profitable on Wilson clay loam and Denton clay. The margin of profit is quite satisfactory on Houston clay, Bell clay, and Irving clay. Fertilizers on Houston black clay and Wilson clay paid their cost in increased cotton yields and yielded small profits when the returns for all years of the experiments are considered. Soils in the first group seem to offer possibilities for the practical introduction of commercial fertilizers on a field scale. On soils of the last group specific trials on a small scale should precede and serve as a guide for more extensive utilization. The soils of the second group occupy an intermediate position in this respect.

Furthermore, as demonstrated by the results reported, fertilizers, through their effect in accelerating maturity, furnish insurance against excessive losses from the root-rot disease, insect damage, and deteriorating influences to which the cotton crop is subject as the season progresses. They have also been shown in many instances to effect a direct, though gradual, control of root rot itself. In the degree to which these effects are manifested the margin of profit will be increased. This will contribute to maximum efficiency of production.

A number of other factors have been brought out in this study which have bearing on the economics of fertilizer use. Among these are the following:

Evidence has been presented to show that on some of the more productive soils lower acre rates of application than 600 pounds might be used with almost equal effect. Such applications would, of course, permit wider margins of profit.

Marked residual effect of fertilizers has been demonstrated on practically all of these soils. Accordingly, the current year's increase in yield cannot be taken as the full measure of benefit of a single application.

Fertilizer-distributing machinery attached to the cotton planter has proved practicable. This will reduce the overhead cost of application to a low level.

Work with concentrated fertilizers has shown that some have special value under these conditions. These materials may reasonably be expected to cost less per pound of plant food than ordinary commercial goods.

It has been possible to increase the effectiveness of fertilizers by better adapted placement. Further knowledge of the placement factor may permit even greater economies.

The use of larger particle size than is common in ordinary fertilizers offers promise of increasing their effectiveness.

These factors must be given consideration in any attempt to forecast the value of fertilizers for the soils of this section.

RELATION OF FERTILIZER USAGE TO OTHER MEANS OF CONTROL OF COTTON ROOT ROT

As pointed out in the introduction, extensive investigations on the control of cotton root rot thus far reported have not developed means of actual eradication of the disease on a field scale. While attainment of such an end is much to be desired, it would appear that, for the present, the most hopeful prospect is so to plan cultural operations in the production of cotton that losses may be evaded or offset to as great a degree as possible. Practices developed by the work of other investigators and in the experiments described herein may be made to contribute to such control of root rot as to insure production of a crop, with minimum loss, even though infestation by the disease is still prevalent.

Crop rotation has been advocated as a control measure and experiments have demonstrated that, under many conditions, introduction of appropriate noncotton crops in the crop sequence is effective in reducing losses (*11*, *12*, *13*, *14*, *66*, *70*). For this purpose sorghum has proved among the most effective crops on root-rot-infested ground. Clean fallowing, in certain instances, has likewise been effective (*14*, *31*, *32*, *70*). Deep tillage in late summer, as exemplified in subsoiling experiments by this division and others (*13*, *14*) has greatly reduced the loss of crop in the succeeding season.

Without question, the above-described effects of fertilizers in evading, counterbalancing, or directly reducing losses from root rot will be enhanced and will attain their maximum when such fertilizers are judiciously employed in conjunction with these other treatments. It is entirely conceivable that a rational practice combining fertilizer usage with one or more of these cultural treatments, as conditions dictate, through material control of cotton root rot from year to year, may eventually, as a cumulative effect lead to actual eradication of the disease in many fields so handled.

SUMMARY

A progress report is presented of the results of field experiments on the relation of fertilizer usage to the control of cotton root rot, conducted in the black-land prairie section of Texas during the period 1928 to 1931, inclusive. These experiments were designed to test the effects of fertilizer treatments upon the growth and yield of the cotton crop under conditions of root-rot infestation, and upon the resistance of plants to the disease. The tests were conducted in cooperation with cotton growers and on field stations of the Bureau of Plant Industry and the Texas Agricultural Experiment Station; and they were so distributed as to cover the most prevalent soil types and the variations in climatic conditions characteristic of the section.

Fertilizer-analysis experiments, based on the triangle system, with applications of mixtures containing a total of 15 percent of plant food

at a rate of 600 pounds an acre, in some instances 300 pounds an acre, were carried out on representative areas of the several soil types. The data presented include results from five such trials on Houston black clay, each extending through 2 or 3 seasons, and from 1 experiment on Houston clay; 2 years' results on Bell clay; 4 years' results each on Wilson clay and Wilson clay loam; 2 seasons' results on Irving clay; and 3 years' results on Denton clay.

For the section as a whole the greatest fertilizer response, in acceleration of maturity and in increased yields of cotton, has been secured from the combined application of nitrogen and phosphoric acid. Nitrogen alone has usually shown a marked effect on early plant growth and color of foliage; but in only a few cases has such fertilizer given the greatest increase in total yield. A few fields have responded to phosphoric acid alone. For maximum effect on the majority of the soils, however, the two constituents must be present in combination. There has been relatively little response to potash, insofar as plant growth and yields are concerned; and in these respects the element is apparently of minor importance on the black-land soils.

The results on Houston black clay indicate a response to fertilizers relatively high in nitrogen, with increases in yield ranging from 13 to 53 percent, after application of fertilizers containing nitrogen and phosphoric acid in ratios of 1:1, to 3:1. Most pronounced acceleration of maturity resulted from ratios of higher phosphoric acid content, although higher nitrogen ratios were also effective in this regard. Fertilizers applied at a rate of 300 pounds per acre were nearly as effective as the 600-pound rates. The trend of response on Houston clay was similar; but in the instance reported, the magnitude of yield increases was greater than on most of the Houston black-clay fields. In the experiments on Bell clay there was a trend toward pronounced response to phosphoric acid, with marked hastening of maturity and increases in yield of 28 to 34 percent from fertilizers containing a 1:3, to 1:1 ratio of nitrogen and phosphoric acid. On Wilson clay appreciable acceleration of maturity and increases in yield ranging from 19 to 28 percent were obtained from fertilizers containing 6 to 9 percent of nitrogen, 3 to 6 percent of available phosphoric acid, and about 3 percent of potash. Wilson clay loam proved to be the most responsive soil encountered in the experiments, with marked acceleration of maturity and increases in yield ranging from 68 to 117 percent, from ratios high in phosphoric acid. The principal response was to phosphoric acid; but the presence of some nitrogen and perhaps a small proportion of potash in the ratio appeared necessary, particularly after repeated fertilizer treatments. Irving clay also responded to ratios relatively high in phosphoric acid, with marked acceleration of maturity and increases in yield of 23 to 47 percent from 1:3:1 to 2:3:0 or 2:3:1 ratios. On Denton clay marked response was obtained from applications of nitrogen and phosphoric acid in combination, with increases in yield amounting to 48 to 82 percent. Little or no consistent response to any fertilizer ratio was obtained in the experiments on Miller silty clay loam or on the Houston clay loam at the United States San Antonio Field Station.

The data show evidence of an appreciable residual effect of fertilizers as successive applications to the same areas become cumulative. The effectiveness of a given treatment must be judged by the average results over a term of years rather than by a single year's returns.

Results of supplementary experiments with concentrated fertilizer materials, particularly the ammonium phosphates, have shown their marked effectiveness in accelerating early plant growth and maturity in certain seasons. The increases in yield compared favorably with those from ordinary commercial materials; but the results were not entirely consistent, and have not demonstrated the advantages of such concentrated materials over those of lower analysis that might be anticipated on theoretical grounds.

In tests of various sources of nitrogen no decided advantage for any of the common nitrogen carriers was demonstrated.

Marked response to phosphoric acid was obtained in cotton following clean fallow on Wilson clay. The increases in yield were of such magnitude as to contribute materially toward compensating for the loss of crop during the period of fallow.

Application of nitrogenous fertilizers to cotton following crops of sorghum resulted in increased yields of such magnitude as to offset the unfavorable after effects of the sorghum and to provide a further increase in yield.

Evidence is presented to show the importance of the appreciable acceleration of maturity effected by favorable fertilizers in most of the experiments as a means of evading losses of crops due to progressive killing of plants by root rot. Likewise the increases in total yield are in most cases of such magnitude as to more than compensate for losses that would otherwise occur. These two well-defined effects of fertilizers combine to provide means of indirect control of the disease. Instances are cited in which such indirect control has been operative.

Data are also submitted which demonstrate conclusively and relatively consistently a significant reduction in the proportion of cotton killed by root rot where fertilizer treatments have been effective in enhancing plant growth and vigor and in increasing yields of crops. This direct effect of fertilizers, while of insufficient magnitude to be of economic importance per se, is highly significant as reflecting the influence of soil fertility in general and of the use of fertilizers on the effective virulence of the root-rot disease. It also implies that the continued use of appropriate fertilizers in successive years, together with the application of other measures designed to restore or maintain fertility may eventually lead to material control.

When such effects of fertilizers are taken into consideration, their use may prove economically practicable and profitable even on soils where the increased yields alone are relatively low. To such degree as the magnitude of all effects can be enhanced by most effective placement, selection of most suitable materials and ratios, and most efficient utilization of minimum rates of application, to the same degree will the practicability of fertilizer usage on these soils be enhanced, and the greater will be the profitableness on more responsive soils that already justify fertilizer usage.

The maximum effectiveness of fertilizers in respect to control of cotton root rot will, under many conditions, be attained when they are applied in conjunction with crop rotation, fallowing, modified tillage, and other cultural treatments. Cumulatively, continued control by such measures combined may eventually lead to eradication of the disease in fields so handled.

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